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UNITED STATES
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HYDRAULIC MODEL STUDIES OF THE SPILLWAY AND OUTLET WORKS FOR PRINEVILLE DAM CROOKED RIVER PROJECT, OREGON

Hydraulic Laboratory Report No. Hyd-452

DIVISION OF ENGINEERING LABORATORIES

COMMISSIONER'S OFFICE
DENVER, COLORADO

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UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

Commissioner's Office--Denver
Division of Engineering Laboratories
Hydraulic Laboratory Branch
Denver, Colorado
Date: June 1, 1959

Laboratory Report No. Hyd-452
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Subject: Hydraulic model studies of the spillway and outlet works for Prineville Dam--Crooked River Project, Oregon

PURPOSE

Hydraulic model studies were made to determine whether a combination spillway and outlet works stilling basin would be satisfactory for Prineville Dam, and to insure that the approach channel, crest, and chute of the spillway, the bifurcation and tunnel of the outlet works, and the junction of the spillway and outlet works would perform satisfactorily.

CONCLUSIONS

Spillway

1. A combination stilling basin for both spillway and outlet flows can be used satisfactorily (Figure 4).

2. The initial spillway approach channel and curved, vertical guide walls are satisfactory (Figure 3).

3. The crest pressures are positive and steady, and therefore satisfactory (Figure 11).

4. The water moved fairly smoothly and evenly down the spillway chute and approached the stilling basin in an evenly distributed sheet at all flows above about 400 cfs (Figure 12F).

5. Air vents into the chamber under the cover slab at the junction of the outlet tunnel and the spillway are required to prevent flutter in the water passing over the junction opening (Figure 4, Sections A-A and E-E).

6. The stilling basin performs satisfactorily with spillway flows with or without the proposed dividing walls. The floor pressures are positive when the tail water elevation is at or near normal level (Figure 15A). There is considerable splashing and wave action in the basin.

7. The initial chute blocks with only moderate rounding on the top edges produced negative pressures in the cavitation range when high

spillway flows occurred (Figure 16B and C). A modified block using more generous curves produced more satisfactory pressures (Figure 16D and E).

8. The riprapped left bank of the river channel should be warped from the 2:1 slope at the end of the basin to a 3:1 slope 100 feet downstream. Erosion is not expected to be severe in the channel (Figure 28C).

9. "Slug flow" or roll waves will occur on the spillway when discharges of less than about 400 second-feet occur (Figure 17). These roll waves will produce waves and splashing in the stilling basin.

Outlet Works

1. The bifurcation upstream from the outlet gates, with a circular-nosed dividing pier with a 30-foot radius joining the tapered and parallel wall sections, and a circular arc roof, is acceptable for prototype use (Figure 19). This design is adequate because the 6-foot high gates will be restricted to a maximum opening of 5 feet 6 inches to limit the stream flow, and the resulting back pressure holds the rather severely reduced local pressures to positive values. Better pressure conditions occur on the bifurcation using elliptical curves (Figure 18).

2. The flows in the tunnel are satisfactory with either symmetrical or unsymmetrical operation of the gates (Figure 20). The humped floor effectively damps the tendency of the flow to swing from one side of the tunnel to the other.

3. The cover slab at the junction of the outlet tunnel and spillway should be terminated at Station 11+95.96 to prevent interference with the outlet flows (Figure 21).

4. The pressure on the initial chute block and floor are satisfactory with outlet works flows when the tail water elevation is at or near the normal level (Figure 15). Better pressure conditions are obtained with the more rounded chute blocks shown in Figure 16D.

5. Dividing walls in the stilling basin are essential for outlet works flows (Figure 23). The initially proposed 28.5-foot high walls extending to Station 13+41.67 are satisfactory, and the basin performance is good (Figures 24 and 25).

6. The stilling basin dividing walls will be subjected to fluctuating hydraulic loads, particularly during outlet works flows (Figure 22). This factor must be taken into consideration in the wall design.

7. Adequate riprap protection must be provided along the left bank of the outlet channel to forestall riverbed material being picked up by currents, swirled around within the basin, and deposited between the dividing walls and the outer walls.

8. As was the case for spillway flows, the bank of the riprapped left river channel should warp from the 2:1 slope at the end of the basin to a 3:1 slope 100 feet downstream to reduce erosion (Figure 28B).

ACKNOWLEDGMENT

The designs discussed, developed, and tested in this laboratory study reflect the cooperative efforts of the Spillway and Outlet Works Section of the Dams Branch, and the Hydraulic Laboratory.

INTRODUCTION

Prineville Dam is the principal unit of the Crooked River Project and is located on the Crooked River about 21 road miles southeast of the town of Prineville, Oregon. The reservoir will store water during heavy runoff periods to relieve flood danger and damage, and to provide water for irrigation later in the growing season. The dam is an earthfill structure with a crest length of about 790 feet and a height above the riverbed of about 180 feet (Figure 2). An uncontrolled overflow spillway and a gate-controlled outlet works are provided in the right abutment.

The spillway consists of an excavated approach channel, an ogee crest, and a 475-foot long concrete chute that ends in a jump-type stilling basin (Figure 3). The 20-foot wide crest is set at elevation 3234.80 and is designed to pass 8,120 cfs. The 54-foot wide by 100-foot long stilling basin contains chute blocks at the upstream end and a dentated sill at the downstream end to aid in creating a hydraulic jump with high energy dissipation (Figure 4). An excavated channel carries the water downstream to the existing river channel.

The outlet works consists of an inlet structure, an 11-foot 0-inch-diameter circular tunnel extending to the dam axis, a symmetrical wye branch or bifurcation containing 4-foot by 6-foot emergency and service slide gates, and a modified horseshoe tunnel terminating in the spillway stilling basin (Figures 5, 6, and 7). The alinement of the outlet conduit from the service gates to the spillway placed the conduit directly beneath the spillway. This permitted using the same stilling basin for the spillway and outlet works.

The outlet works flows may be as high as 3,529 cfs and as low as 10 cfs, the latter flow fulfilling requirements of the Fish and Wildlife Service. All reservoir releases will be into the river channel below the dam and part of the flow will be taken out at a proposed diversion structure 15 miles downstream. The remainder will pass over the diversion dam and continue downriver to satisfy prior water rights.

Single stilling basins for handling both spillway and outlet works flows have been used on a number of other Bureau of Reclamation structures. A recent example is Paonia Dam.1/ In these previous multiple-use

1/ "Hydraulic Model Studies of Paonia Dam Spillway and Outlet Works," Report No. Hyd-444, by G. L. Beichley.

basins, the outlet flows occupied only a limited part of the stilling basin width and were small compared with the spillway flows. The outlet flows therefore did not have enough energy to cause troublesome eddies or scour beyond the end of the basin, and basins designed primarily for spillway flows were satisfactory for both flows.

In the case of Prineville Dam, the outlet works has nearly half the capacity of the spillway and enough energy to produce powerful eddies and currents beyond the basin. Thus there will be sufficient energy to cause serious damage. This was taken into account in the design of the basin and dividing walls were provided to produce an outlet works basin within the main basin. The outlet conduit was flared as it approached the basin so that at maximum flow the entering depth, d_1, would be about the same as for the maximum spillway flow and compatible with the tail water depth, d_2, made available in the basin. The final width of the expanded section at the end of the sloped chute (Station 12+75.00) determined the spacing of the parallel 66-foot 8-inch long walls in the horizontal part of the basin (Figure 4). Upstream from Station 12+75.00 the walls were placed in line with the spreading water in the diverging spillway chute.

Hydraulic uncertainties were involved in the design of the basin and dividing walls. For example, it was not known if the wall spacing and length were satisfactory, or what flow conditions would occur in the spillway approach channel. It was also difficult to predict the river channel scour and the flow and pressure distribution in the basin and the outlet works bifurcation. To obtain answers to these design questions, hydraulic and air model studies were made. The equipment used and the results obtained in the course of these studies are described in this report.

THE MODELS

Most of the tests were made on a 1:24 scale hydraulic model (Figure 8). Additional tests on details of the outlet works bifurcation were made on a 1:12 scale air model (Figures 18 and 19).

The hydraulic model consisted of an elevated head box that contained the reservoir topography and spillway crest, a long sloping spillway chute, and a tail box at floor level that contained the stilling basin and a portion of the channel to the river. The head box topography included part of the right side of the earth dam and the hillside at the right abutment. It was formed by troweling concrete onto wire lathe that was held to the proper contours by wooden templates. The approach channel was formed as shown in the initial design (Figure 3). The spillway crest was made of concrete that was smoothly troweled to conform with accurately shaped metal screeds. After the concrete had cured, the surface was lightly ground to produce a smooth, dimensionally stable section. The spillway chute and the stilling basin were made of wood in sections convenient for handling and alining. The river channel was first formed entirely of loose plastering sand. Later riprap was added on the left slope near the basin, and concrete was placed in the center and on the right side to represent the solid rock at the site.

The outlet conduit extended from beneath the spillway crest to the junction with the spillway at the stilling basin. The conduit floor was carefully worked from straight-grained redwood. The top and sides were made of transparent plastic that had been heated and shaped over wooden molds. Lightweight, simplified, sheet metal slide gates produced typical outlet works releases.

Care was taken in constructing the spillway chute so that smooth, straight flow surfaces were obtained. Slight irregularities found during assembly of the model were smoothed out. The chute was then treated with several coats of waterproofing, resanded, and finally painted with a glossy oil-base paint to produce a watertight and exceptionally smooth flow passage. These precautions were necessary to keep the friction as low as practicable. However, even with these precautions it was known that the friction would be greater in the model than it should be to represent prototype conditions. To compensate for the extra friction, an additional vertical fall of 0.5 foot was provided by extending the length of the chute between the crest and the vertical curve. This extra fall was shown by calculation to be enough to produce the proper equivalent velocity at the entrance to the stilling basin. Model tests showed that a velocity equivalent to 89 feet per second, prototype, was obtained at Station 12+01.8. This compares with a computed value of 83 feet per second with a Manning's "n" value of 0.011, and a velocity of 98 feet per second with an "n" value of 0.008.

Pertinent details, such as stilling basin chute blocks and a dentated sill, were included in the model. Piezometers were placed along the centerline and the right side of the spillway crest. Other piezometers were placed on the trajectory curve of the outlet works where it joined the spillway, in a chute block, on the basin floor near the block, and on the basin dividing walls (Figures 8 and 22). The pressures acting at these piezometers were measured by single-leg water manometers. In cases where the pressures fluctuated widely and were negative (below atmospheric), a sensitive pressure cell was used and the pressure fluctuations were recorded electronically.

Point gages were used in the head box and tail box to measure the water surface elevations. Point gage stations were also set up across the chute and along the stilling basin to obtain water surface profiles and cross sections (Figure 12). Water was supplied to the model through the central laboratory supply system which contains calibrated Venturi meters for measuring the rate of flow. After passing through the model, the water was returned to the laboratory reservoir for recirculation.

The pressure distribution on the dividing pier and roof of the outlet works bifurcation was studied on a 1:12 scale model that used air as the flowing fluid (Figures 18 and 19). A 1:12 scale ratio was selected for the air model to obtain reasonably large gates and conduits, and so that tests could be run at sufficiently high Reynolds' numbers to have good model-prototype similarity. The model test section consisted of an 11-inch round to 11-inch horseshoe transition, the bifurcation structure, and simplified outlet control gates. A centrifugal blower was used to supply the air flow. The air was drawn from the atmosphere through flat plate measuring orifices, and was sent through the discharge line to the test section. It discharged freely into the atmosphere after passing through the bifurcation control gates.

INVESTIGATION

Spillway

Approach Channel

Model operation showed that generally satisfactory flow occurred in the preliminary spillway approach channel (Figure 9). The fairly large eddy that developed where flow passed around the point of land at the left of the channel had little effect at the spillway crest. As the flow approached the curved vertical guide walls at the crest, it accelerated and passed between them smoothly and with little wave action. The tops of the left and right concrete approach walls, which were set at elevation 3258.0, were found to be too low for maximum flows and were raised to elevation 3260.0. No other approach channel alterations were necessary because the performance was satisfactory, and any possible cost savings due to reduced excavation would be small. The preliminary design with the raised wall tops is therefore recommended for prototype use.

Spillway Crest

The flow moved smoothly over the crest to continue down the chute (Figure 10). The pressure along the crest centerline and along a line 1-1/2 inches prototype from the right wall were steady and positive (Figure 11A). The relations of reservoir elevation to spillway discharge, and of head on crest to discharge coefficient, are shown in Figure 11B and 11C. The water surface elevations along the approach wing walls and along the spillway centerline are shown in Figure 12A.

Spillway Chute

The flow passed fairly smoothly down the spillway chute, and the cross-sectional water surface at Station 8+41.8 was nearly flat (Figure 12B). The surface was also quite flat in cross section at Station 9+02.8 when the flow rate was 4,060 cfs, but became deeper on the right than on the left as the flow rate rose to 8,120 cfs. At Station 10+01.0, which is about 80 feet past the point where chute divergence begins, a hump at the center and dips near the sides were evident. Farther along in the diverging chute, the flow surface flattened and was very flat at Station 12+01.8 (Figure 12F). Rather high training walls are provided, and there should be ample freeboard at all stations to take care of bulking of the prototype flow due to air insufflation.

Air Vents

The necessity of the 24-inch-diameter air vents into the chamber beneath the cover slab at the junction of the outlet conduit and spillway chute (Figure 4, Sections A-A and E-E) was established by closing the two 1-inch vents provided in the model (Figure 8, Sectional Elevation A-A). The sheet of water passing over the junction continued to pump air out of the outlet conduit and, because the main supply of air closed, began to develop negative pressures in the conduit. The pressure differential between the atmosphere and this negative value forced the sheet of water farther and farther downward, until finally the flow separated at the sides of the opening to admit air. This new supply of air relieved the negative pressures momentarily, and the water sheet sprang upward to its original trajectory. Then the cycle started again, with the result that an undesirable flutter occurred in the flow passing over the junction opening. The action was most pronounced at flows of 2,000 cfs or less. It should be noted that the above tests were run with the small air vents in the downstream bodies of the outlet gates fully opened.

An additional test was made where an extra 1-inch-diameter model vent was provided near the outlet gates at the point where the 4-foot by 6-foot outlet tunnels joined the 11-foot horseshoe tunnel. The jet flutter persisted, but to a lesser degree. When the two 24-inch vents at the spillway junction were opened, the flutter disappeared entirely. The two 24-inch junction vents are therefore believed necessary in the prototype structure.

Stilling Basin and Channel to River

The performance of the stilling basin with spillway flows was satisfactory (Figures 13 and 14). A slightly higher water surface was noted in the upstream end of the center section of the basin than in the left and right bays (Figure 12G). This occurred because the water in the central portion of the spillway chute passes over the outlet conduit opening. The lack of support at the opening allows the water to fall on a free trajectory and impinge on the invert of the outlet chute. This impingement disrupts the flow to some extent, with the result that the toe of the jump in the center bay is not swept as far downstream as in the side bays.

An upward boil occurred at the end of the basin as the end sill deflected the water upward (Figure 14). No riverbed material entered the basin during spillway flows. Considerable wave action and splashing were noted within the basin, but this must be expected in a hydraulic jump with a Froude number, $\frac{V}{\sqrt{gd_1}}$, of about 12. Waves carried out into the excavated river channel, and scaled-up values indicated a maximum through-to-crest height of 3 feet, with an average height of 1-3/4 feet. The prototype waves may be larger than the scaled-up movel waves, but should not be troublesome.

Considerable erosion occurred on the downstream channel banks when no riprap or rock protection was provided. Very little erosion occurred on the channel invert or on the banks upstream from the end of the cantilevered left basin wall. A 1-1/2-inch thick layer of 3/4-inch gravel was placed on the left bank and on part of the invert, and concrete was placed to represent rock on the remainder of the floor and right bank (Figure 27). The erosion was greatly decreased, but some still occurred on the left bank at about Station 14+50. The bank was changed to warp from the 2:1 slope at the end of the basin (Station 13+75) to a 3:1 slope at the end of the riprap (Station 14+75) (Figure 28A). Only minor erosion occurred with the flatter slope (Figure 28).

The margin of safety on tail water elevation for spillway flows was determined by lowering the water as much as the model construction permitted, or 5.2 feet below normal, prototype. The basin continued to handle the flows, and the safety factor was considered satisfactory.

Pressures were measured on areas believed to be critical on the chute, on the side walls of the outlet conduit at its junction with the spillway, on the chute blocks, and on the floor immediately downstream from a chute block (Figure 8). Tabulated pressures, as obtained by single-leg water manometers, and expressed in feet of water, prototype, are presented in Figure 15A. All the above piezometric pressures were positive or about atmospheric when the tail water elevation was normal. Lower pressures occurred on the floor and on the ends of the chute blocks when the tail water was lowered 5.2 feet for spillway flows, and 2.5 feet for outlet works flows. Record traces of pressure fluctuations obtained by means of the electronic pressure cell are presented in Figure 15B.

More detailed studies of the chute block pressures were made using a metal block fitted with 13 piezometers (Figure 16A, B, and D). The tests were made with normal tail water, maximum spillway discharge, and with the outlet tunnel portal in the spillway covered so that undisturbed flow reached the blocks. Tests were also made with the cover removed with outlet works flows. Piezometers 1 and 2, located on the midpoint of the curved surface connecting the block top and left side, showed severely subatmospheric pressures (Figure 16C).

A modified block using more gradually curved surfaces (a 1:5 ellipse in the direction of flow) showed better pressures (Figure 16D and E). The lowest pressures occurred with spillway flows and were found at Piezometer 1 at the beginning of the curve and at Piezometer 9 on the downstream face. No serious negative pressures occurred with outlet works flows, apparently because of the lower flow velocity. The modified block using the 5:1 elliptical curve, with the semiminor axis about one-fourth the distance between the blocks, was believed acceptable for prototype use because at all outlet works flows and at all but the very highest spillway flows, the pressures were well above the cavitation range. At the highest spillway flows where instantaneous pressures occasionally approach vapor pressure, operation would be of short duration and any possible damage would be light. In addition, considerable air would be entrained in the hydraulic jump to cushion cavitation and restrict erosion. The block shown in Figure 16D is therefore recommended for the basin.

Small Flows

At flows between 0 and 400 second-feet, roll waves or "slug flow" will occur in the spillway chute (Figure 17). This is a common feature on long steep chutes when the flow depth is small. The waves rolling down the chute will enter the basin pool with considerable energy and create waves that continue out into the river channel. It is expected that the waves will not appreciably damage the riprapped surfaces, but that spray and splashing may overtop the basin walls.

Outlet Works

Bifurcation at Outlet Control Gates

The first bifurcation tested on the 1:12 scale air model was made with an elliptically-shaped pier nose and roof (Figure 18A). With both gates fully opened and a flow rate equivalent to 3,529 cfs prototype, the pressures were positive at all piezometers except those near the tangent points where the 50-foot radius curves meet the parallel sides (Figure 18B). When one gate was fully opened and the other was fully closed, the pressures just around the point of the nose decreased but remained quite strongly positive (Figure 18C). The pressure in the area where the 50-foot curves met the parallel walls continued to be low.

It was then learned that the 6-foot high gates were to be limited to a maximum opening of 5.5 feet to restrict the stream flow. The partial obstruction created by this limited opening would maintain considerable back pressure in the tunnel. The bifurcation was retested with the gates set to represent 5.5-foot openings, and all pressures were found to be positive and satisfactory (Figure 18D and E).

A more simple design for the bifurcation was then proposed. It consisted of a pier with a circular rather than an elliptical nose, tapered sides, 30-foot radius curves connecting the tapered sides to the parallel ones, and a circular instead of an elliptical roof (Figure 19A). As expected, due to the more abrupt curvatures, the pressures dropped to lower values at the nose, in the areas where the 30-foot radius curves met the parallel walls of the pier, and at the downstream end of the curved roof (Figure 19B and C). However, due to the back pressure produced by the 6-foot 0-inch gates opened only 5 feet 6 inches, the pressures on the pier and roof remain positive for all operational gate openings and discharges (Figure 19D and E). The simpler design using circular curves is therefore acceptable for prototype use.

Flow in the Tunnel

The flows released by the control gates discharge into a long, modified horseshoe tunnel that extends to the stilling basin. When both model gates were operated at the same opening, the flow was symmetrical and reasonably smooth through the full length of the tunnel (Figure 20B and D). The disturbance or ridge created when the flow from the two gates came together after passing the dividing pier was not excessive. As the ridge moved downstream, it dropped and spread to the sides of the conduit. This raised the water surfaces at the walls. The higher water surfaces at the walls then worked back to the center to again form a slight ridge. This alternating flow pattern was superimposed on the general downstream flow and affected, to a moderate degree, the flow reaching the stilling basin. A slightly ridged surface existed at the basin in the model, but the ridge was so small that the flow was considered satisfactory.

When only one gate was operated, or when the gate openings were unsymmetrical, the deeper flow tended to swing toward the opposite side of the tunnel and ride up the wall (Figure 20A and C). It then dropped down and swung across the tunnel to climb the other wall. The cycle was repeated several times as the flow traveled the length of the tunnel, but the severity rapidly decreased. Thus, the flow was nearly flat when it reached the stilling basin. The pronounced damping effect that controlled this swinging action was produced by the upward hump at the center of the tunnel floor (Figure 8, Section E-E). This hump was developed in previous model studies and has been used effectively on a number of structures.

Piezometers were installed on the floor just downstream from the line where the 1:36 upslope near the end of the bifurcation intersected the humped floor of the tunnel (Figures 7 and 8, Section B-B, Detail A). The pressures were positive at all heads and gate openings, and averaged slightly less than the hydrostatic heads.

Portal Conditions

Critical flow conditions occurred in the preliminary design at the point where the outlet works tunnel emerged through the spillway chute. This was due to the fact that the cover slab extended a little too far downstream (Station 11+98.75) and restricted the outlet opening. As a result, the flow (4,080 cfs during the first tests) struck the slab heavily and occasionally caused the water to back up and partially fill the tunnel (Figure 21). This action produced heavy loads on the slab and poor flow conditions into the basin. Once the flow backed up into the tunnel, it remained there until the outlet gates were throttled appreciably. Then the tunnel cleared itself and free flow was again established.

The interference of the roof was reduced by cutting the slab back 3 feet along the slope (Station 11+95.96) to increase the passage height. This change allowed the initial 4,080-cfs discharge to pass without appreciable interference. The final outlet works maximum flow, which was reduced to 3,529 cfs by limiting the gate travel, passed easily through the opening with only heavy spray striking the cover. The spillway flow at the stilling basin, while adversely affected by shortening the slab, was still satisfactory and the shorter cover is recommended for prototype use.

Air Vents

The effect, with outlet works flows, of the 24-inch air vents into the chamber under the cover slab (Figure 4, Sections A-A and E-E) was determined by plugging the 1-inch model vents. This left only the normal vents at the outlet gates to supply air. The pressure within the tunnel immediately dropped to somewhat lower values, but the pressures and performance remained satisfactory. The two 24-inch-diameter vents were, therefore, not necessary for outlet works flows but, as previously shown, were necessary for spillway flows.

Chute and Basin Pressures

All pressures measured on the chute were positive and satisfactory (Figure 15A). Also, at normal or near normal tail water elevations, the chute block and floor pressures, as recorded by water manometers, were satisfactory (Figure 15A). With the tail water 2.5 feet below normal, the chute blocks remained covered by the toe of the hydraulic jump, but several slightly negative pressures occurred. Pressure cell records are shown in Figure 15C and D. All pressures were measured with the flow velocity in the model equivalent to 77 fps, prototype, at Station 11+60. This corresponded to the computed velocity using a Manning's "n" of 0.008, and is as high a velocity as could be reasonably expected in the structure.

The pressures acting on the inner surfaces of the stilling basin dividing walls were also measured during outlet works operation. Piezometers were placed in the right hand wall (Figure 22A), and measurements were made with a strain-gage-type pressure cell and a recorder. The greatest fluctuations and highest pressures occurred near the upstream end of the basin close to the floor (Piezometers 8 through 12). These higher pressures and greater fluctuations were expected because of the hydrostatic head of water acting on the surfaces, and because the most violent portion of the hydraulic jump is at the basin entrance and along the floor. A faster chart speed was used for recording these pressures than was used for the ones measured higher upon the wall. The pressure traces obtained at the higher elevations showed the moderating effect of the jump pool. At Piezometers 6 and 7, which were intermittently covered with water, the pressures were approximately atmospheric and fairly constant.

Movement of the intermediate dividing walls was noted during model operation. This movement consisted of an irregular inward and outward motion of the wall tops, relative to the basin centerline, and was most pronounced at the downstream ends. No attempt was made to represent the prototype wall rigidity in the model. The movement was considered important and it was discussed at length with the designers so that adequate measures could be taken. Typical pressure fluctuations on the walls are shown on the records of Figure 22.

Stilling Basin and Channel to River

Tests showed that intermediate dividing walls within the basin were essential for properly handling the outlet works flows. No hydraulic jump formed when there were no walls to restrain the flow, and the jet continued through the basin. In addition, the jet was unstable and moved to one side or the other of the basin and formed a strong eddy that pulled riverbed material into the basin (Figure 23). The energy dissipation was poor, the wave action great, and the river channel erosion severe. The only flow conditions that were in any way acceptable were low discharge at moderate and low velocities.

With the 28.5-foot high walls installed, the flow conditions were good (Figures 24 and 25). A good hydraulic jump formed with satisfactory energy dissipation and flow redistribution. The wave action in the river channel was appreciable, but not excessive at discharges above about 2,500 cfs. At a discharge of 3,529 cfs, the maximum trough-to-crest height, as scaled up from the model, was about 3 feet, and the average wave height was about 1-1/2 feet.

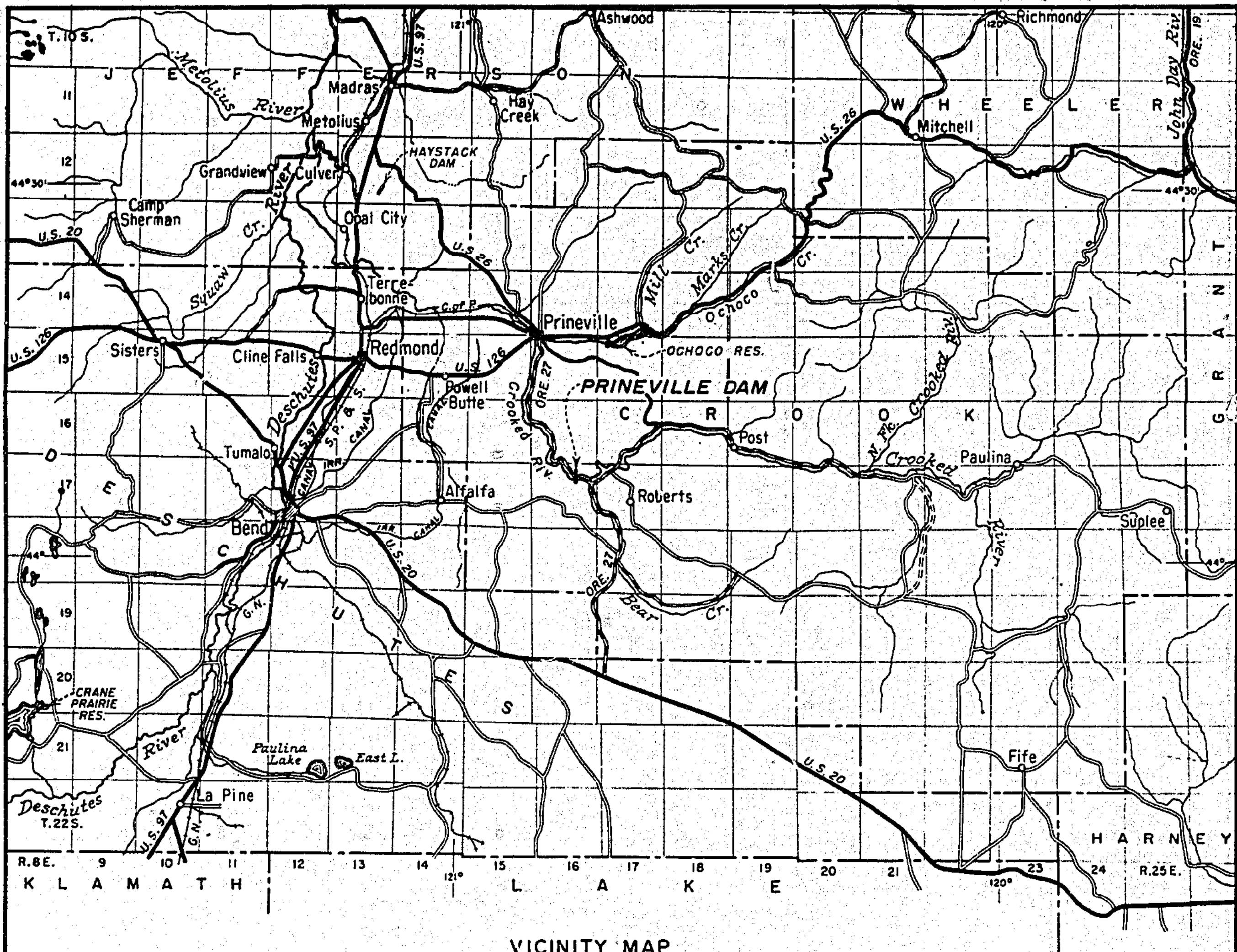
Sand from the loose sand bed first used in the model river channel was picked up, carried into the basin, and swirled around violently. It was then deposited between the intermediate and outer walls (Figure 26A). This bed material circulation would most certainly result in objectionable abrasive erosion on the basin floor and walls. To eliminate the problem, an attempt was made to reduce or stop the currents that picked up the material. The dividing walls were first extended to the end of the basin at their full height of 28.5 feet. No bed material was picked up with this design, but flow conditions were poor (Figure 26C). The toe of the jump moved downstream dangerously close to the chute blocks, and high velocity currents carried through to the end of the basin where the end sill deflected them upward in a severe boil. Wave action was heavy in the river channel. The basin performed well with spillway flows.

When the height of the wall extensions was reduced to 18 feet, water poured in over the wall tops. The jump moved upstream a little, and the violence of the boil was reduced slightly (Figure 26D). In spite of these small changes, the flow conditions and waves were still too rough to be acceptable. Furthermore, large quantities of riverbed material were deposited in the basin (Figure 26B).

Fortunately, from the point of view of bed material circulation, the channel from the basin to the river is excavated partially through rock. The remaining excavation will be protected by riprap. When the model channel was rebuilt to include this rock and riprap (Figure 27A), tests showed that no bed material was carried into the basin, and no deposits were built up (Figure 27C). A few pieces of riprap clustered together on the downstream face of the end sill, but did not move about. It thus appeared that with adequate riprap protection, there would be no serious problem with abrasion and deposits.

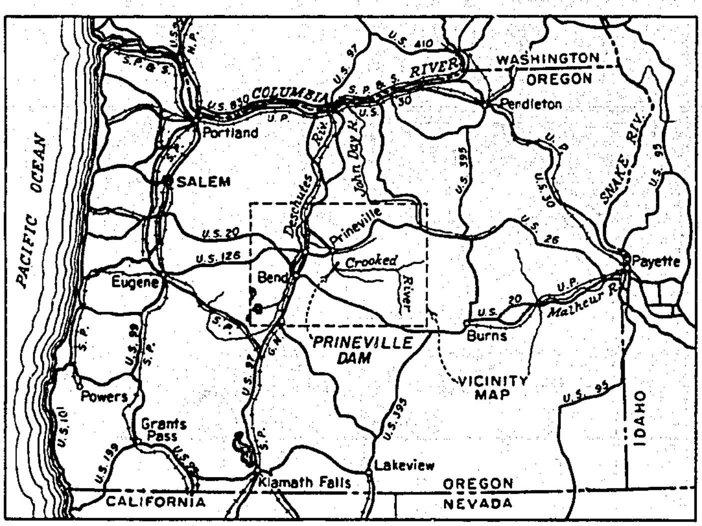
Some movement of the riprap pieces occurred on the downstream portion of the 2:1 riprap slope at higher outlet works flows. This movement was similar to that found with spillway flows. Erosion also occurred on the unprotected slopes farther downstream. The riprapped bank was, therefore, warped from the 2:1 slope at the end of the basin to a 3:1 slope 100 feet downstream (Figure 28A). Less movement of the rock occurred with this design, and less erosion occurred on the unprotected surfaces farther downstream (Figure 28B). The warped riprap slope is therefore desirable for outlet flows, as well as for spillway flows, and is recommended for prototype use.

FIGURE 1
REPORT HYD. 452



VICINITY MAP

5 0 5 10 15 20 25
SCALE OF MILES



INDEX MAP

EXPLANATION
(Vicinity Map Only)

- OILED OR PAVED ROADS
- GRAVELLED ROADS
- IMPROVED ROADS

N

UNITED STATES
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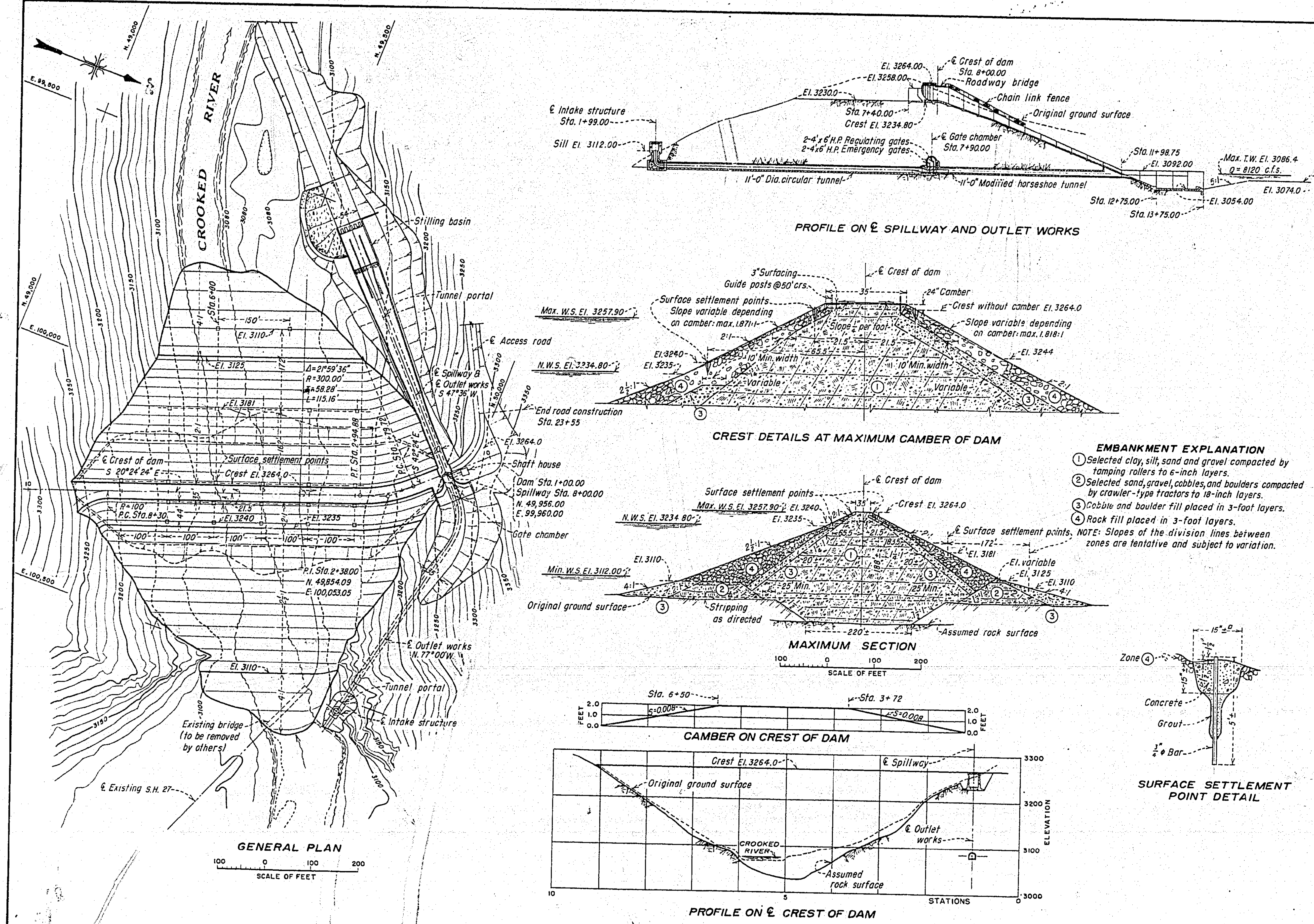
CROOKED RIVER PROJECT-OREGON

PRINEVILLE DAM
LOCATION MAP

DRAWN M.C. SUBMITTED O. L. Kie
TRACED B.F.W. RECOMMENDED T.W. Keener
CHECKED H.W.J. W.L. APPROVED Grant Bloodgood
ASSISTANT COMM. AND CHIEF ENGINEER

DENVER, COLORADO, APRIL 10, 1958 | 113-D-78

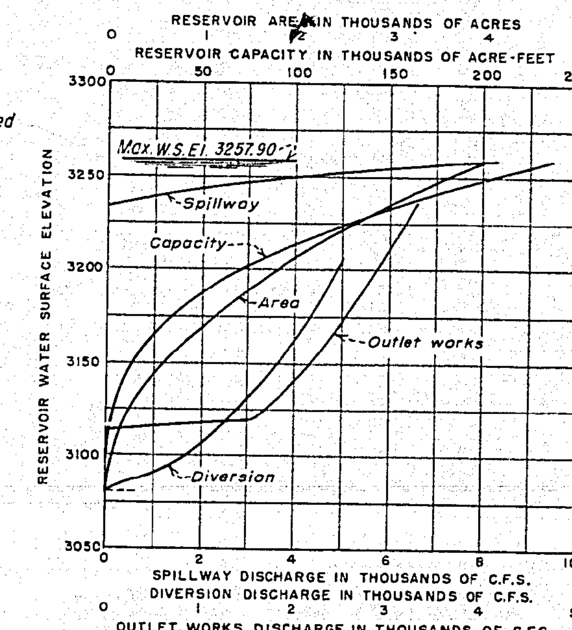
FIGURE 2
REPORT HYD. 452



RESERVOIR ALLOCATIONS

PURPOSE	ELEVATIONS	STORAGE ACRE FEET
Joint use	3211.30 to 3234.80	60,000
Conservation	3114.00 to 3211.30	93,000
Dead & inactive	Streambed to 3114.00	2,000
Total storage capacity		155,000

The combination of 60,000 a.f. of joint use flood control storage plus a surcharge of 79,700 a.f. (Max. W.S. El. 3257.90) together with a spillway capacity of 8,120 c.f.s. is provided to protect against the maximum inflow design flood having a peak of 46,000 c.f.s. and a 9-day volume of 189,300 a.f.



AREA-CAPACITY-DISCHARGE CURVES

9-17-58 REVISED LEFT SIDE OF EXIT CHANNEL DOWNSTREAM OF STA. 13+75.0

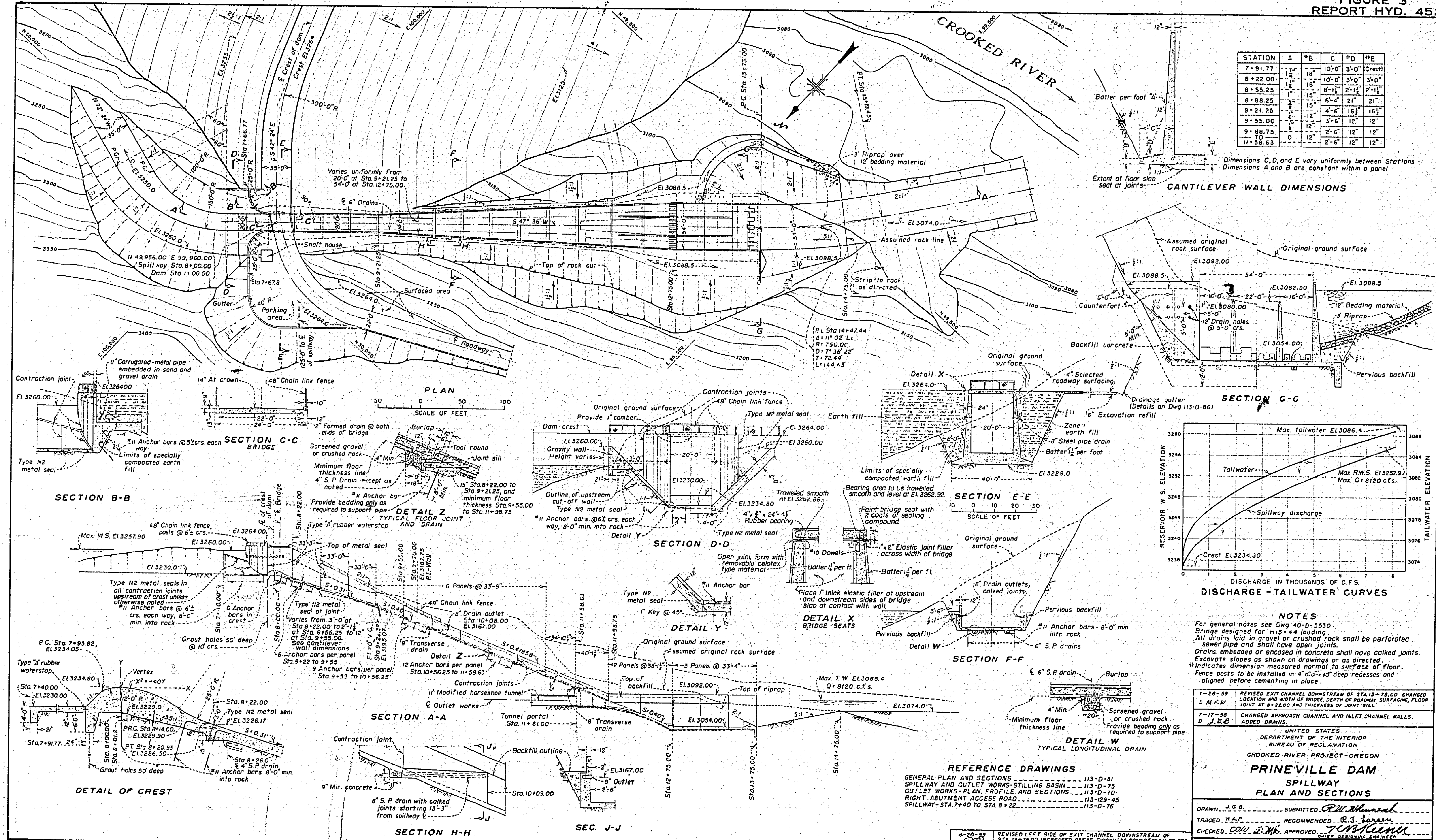
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CROOKED RIVER PROJECT-OREGON

PRINEVILLE DAM

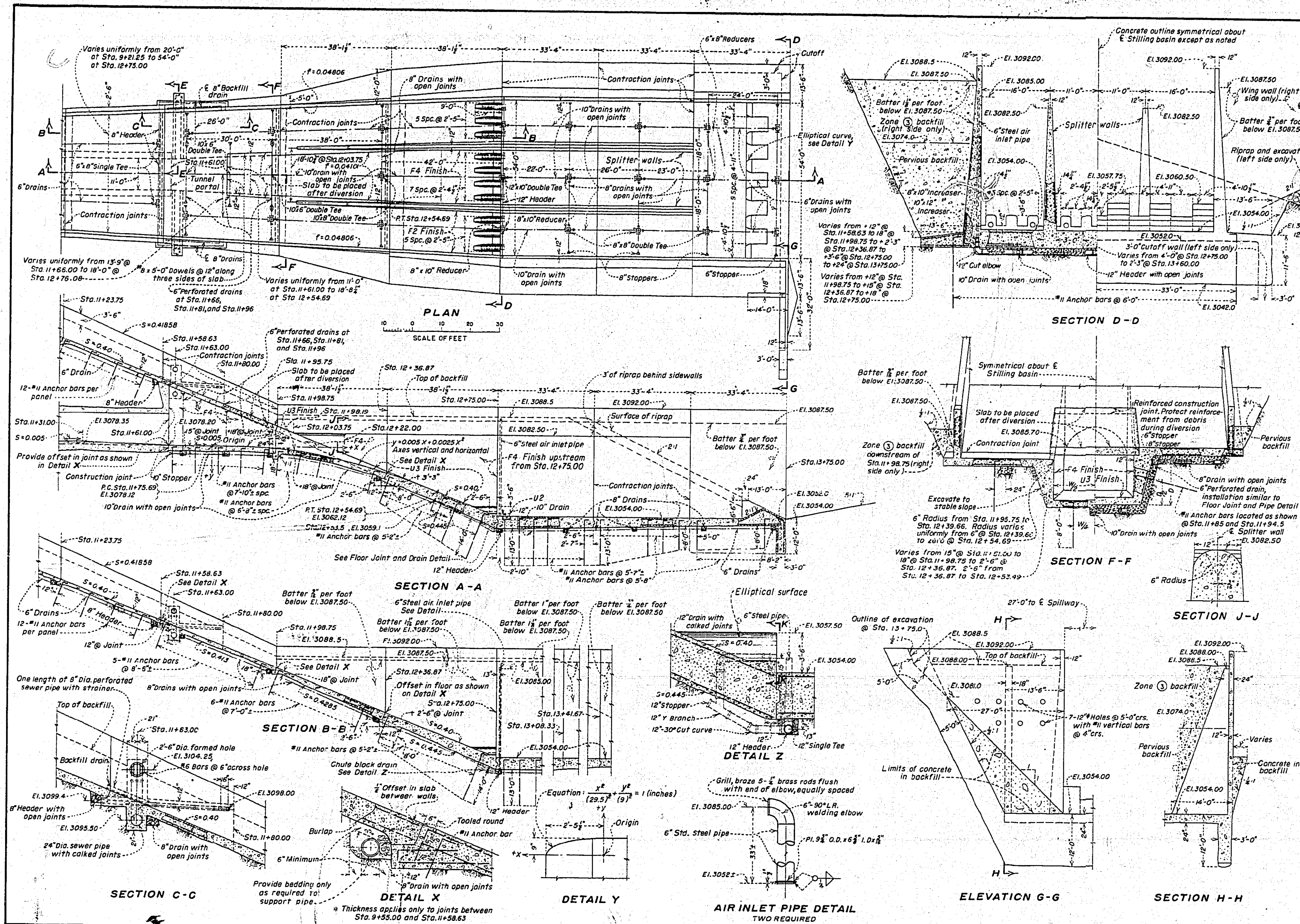
GENERAL PLAN AND SECTIONS

DRAWN H.W.C. SUBMITTED A.J. Lien
TRACED E.E.B. RECOMMENDED T.W. Mermel
CHECKED R.B. W.I. APPROVED Grant Bloodgood ASST. COMM. AND CHIEF ENGINEER
DENVER, COLORADO, APRIL 10, 1958 113-D-81

FIGURE 3
REPORT HYD. 452



STATION	A	*B	C	*D	*E
7+91.77	$1\frac{1}{4}$"	18"	10'-0"	3'-0"	(Crest)
8+22.00	$1\frac{1}{4}$"	18"	10'-0"	3'-0"	3'-0"
8+55.25	1"	15"	8'-$1\frac{1}{8}$"	2'-$1\frac{1}{2}$"	2'-$1\frac{1}{2}$"
8+88.25	$\frac{3}{8}$"	15"	6'-4"	21"	21"
9+21.25	$\frac{1}{4}$"	12"	4'-6"	$16\frac{1}{2}$"	$16\frac{1}{2}$"
9+55.00	$\frac{1}{8}$"	12"	3'-6"	12"	12"
9+88.75 TO	0	12"	2'-6"	12"	12"
11+58.63			2'-6"	12"	12"



STA.	t	a	b
12+75.00	48"	$3\frac{5}{8}$"	$13\frac{1}{2}$"
13+08.33	40"	$3\frac{5}{8}$"	$13\frac{1}{2}$"
13+41.67	32"	$2\frac{5}{8}$"	$11\frac{1}{2}$"

NOTES

For general notes, see drawing 40-D-5530.
Excavate slopes as shown on drawings or as directed.
"f" Indicates tangent of flare angle
† Indicates dimensions measured normal to surface of floor.
Drains embedded or encased in concrete shall have calked joints.
Drains under floor slab shall have open joints.
Stoppers shall be placed to close the ends of all transverse floor drains.
Anchor bars in rock to have minimum embeddment of 8' unless otherwise shown.

REFERENCE DRAWINGS

SPILLWAY-PLAN AND SECTIONS 113-D-69
OUTLET WORKS-PLAN, PROFILE AND SECTIONS 113-D-70

4-16-59 D.-RLB	REVISED ROCK EXCAVATION LINE ON SECTIONS E-E AND F-F. ADDED 6" DRAINS AND REPLACED 8" DRAIN WITH 10" DRAIN ON PLAN AND SECTIONS A-A AND F-F
1-23-59 D M.F.W	REVISED CHUTE BLOCKS
7-17-58 D	REVISED CONCRETE DIMENSIONS, DRAIN LOCATION AND ANCHOR BAR LAYOUT.

UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CROOKED RIVER PROJECT - OREGON

PRINEVILLE DAM

SPILLWAY AND OUTLET WORKS STILLING BASIN

DRAWN R.L.B. SUBMITTED F. M. Holdaway
TRACED E.M.W. RECOMMENDED R. W. Whinnerah
CHECKED APPROVED R. J. Larsen
ACT. CHIEF, DAMS BRANCH
DENVER, COLORADO, APRIL 15, 1958. 113-D-75

FIGURE 5
REPORT HYD. 452

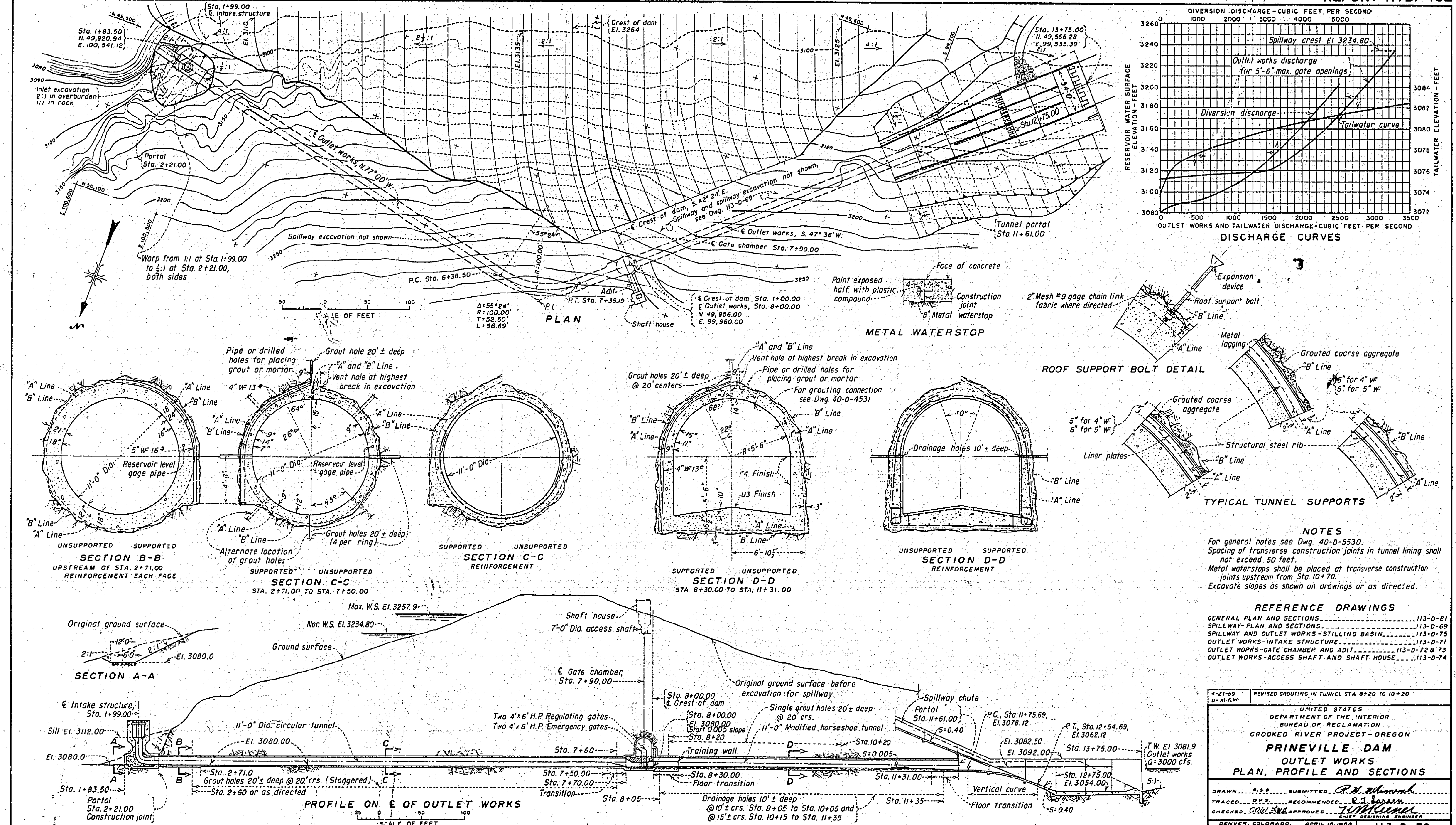
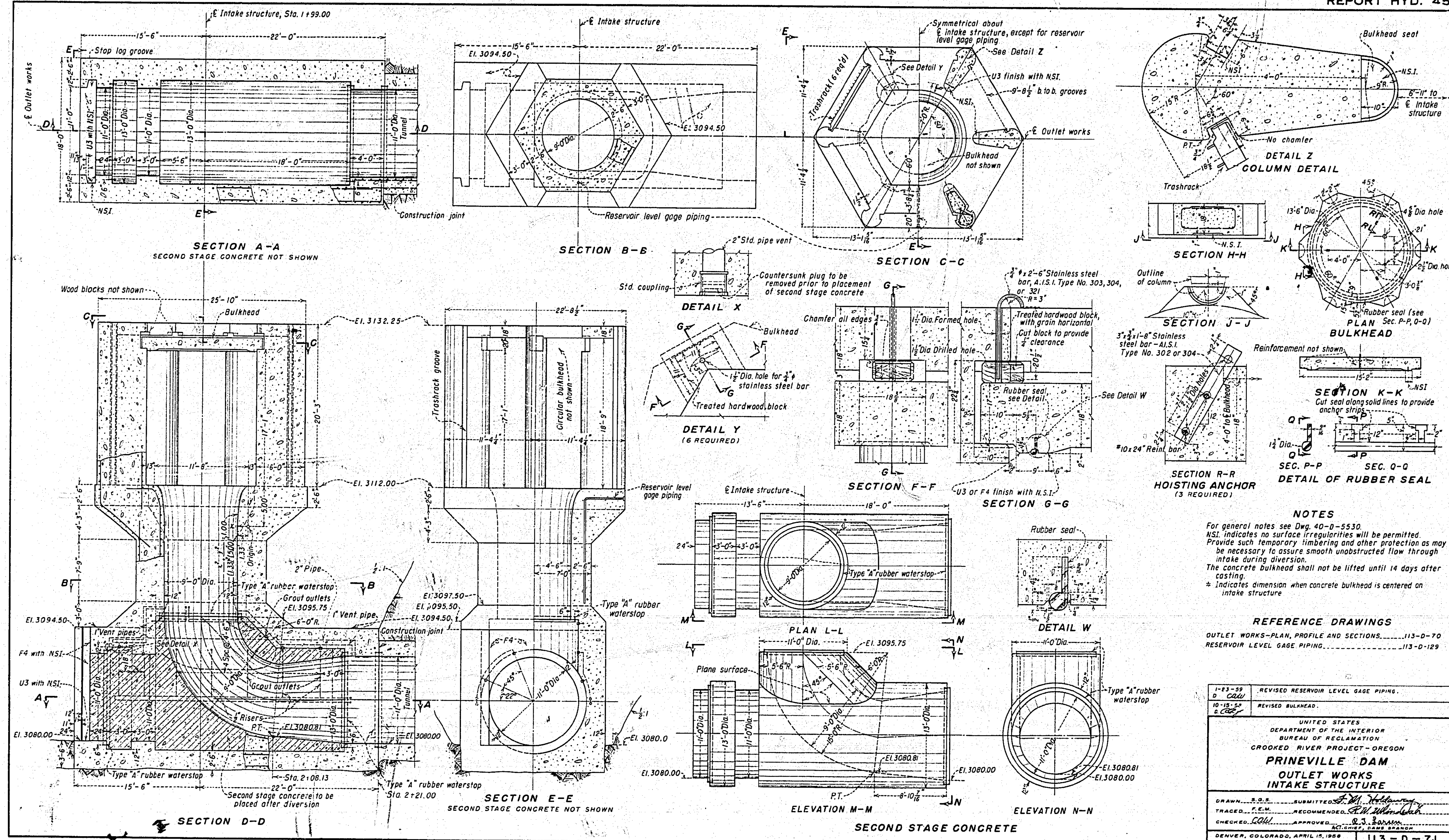
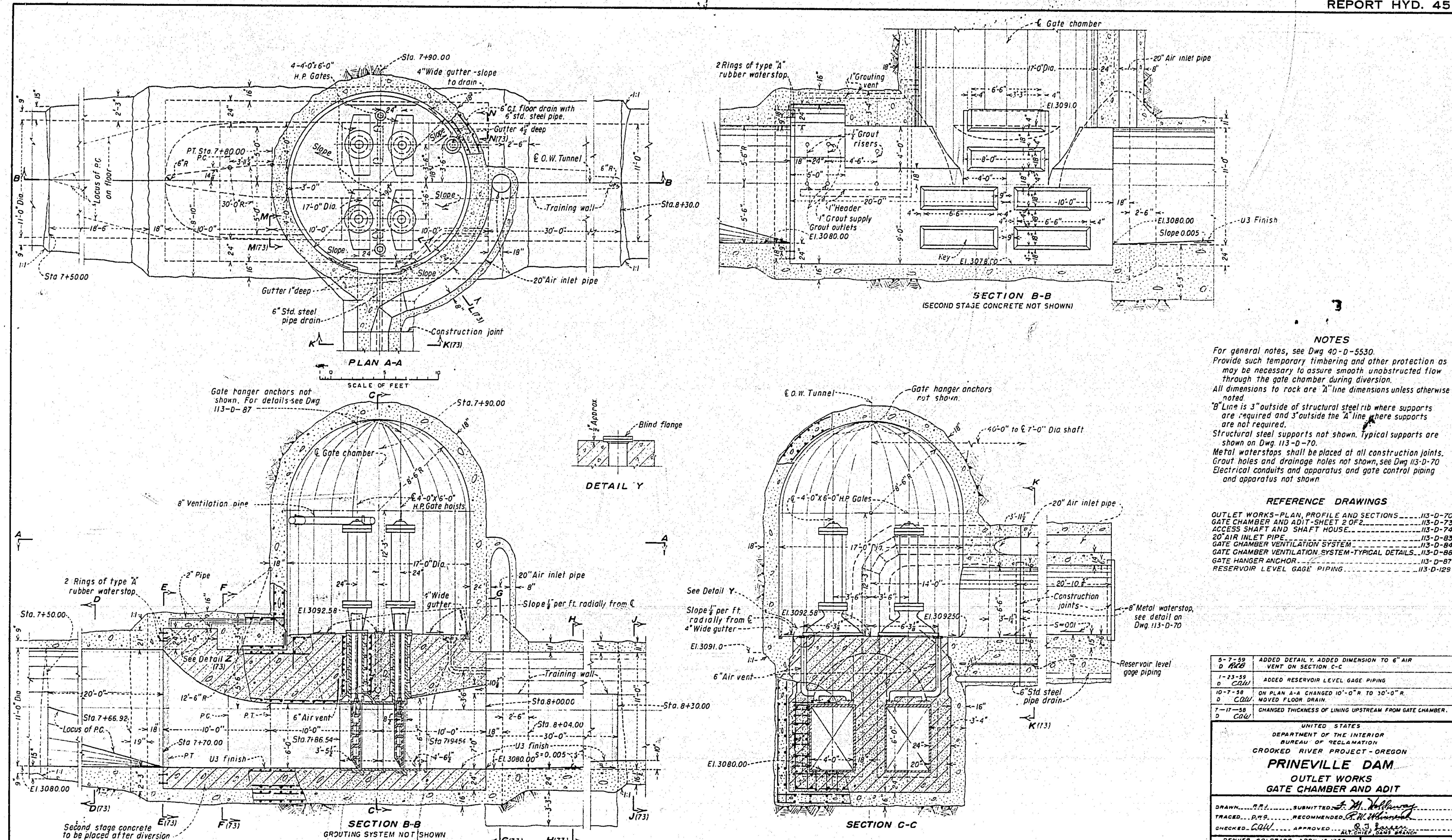
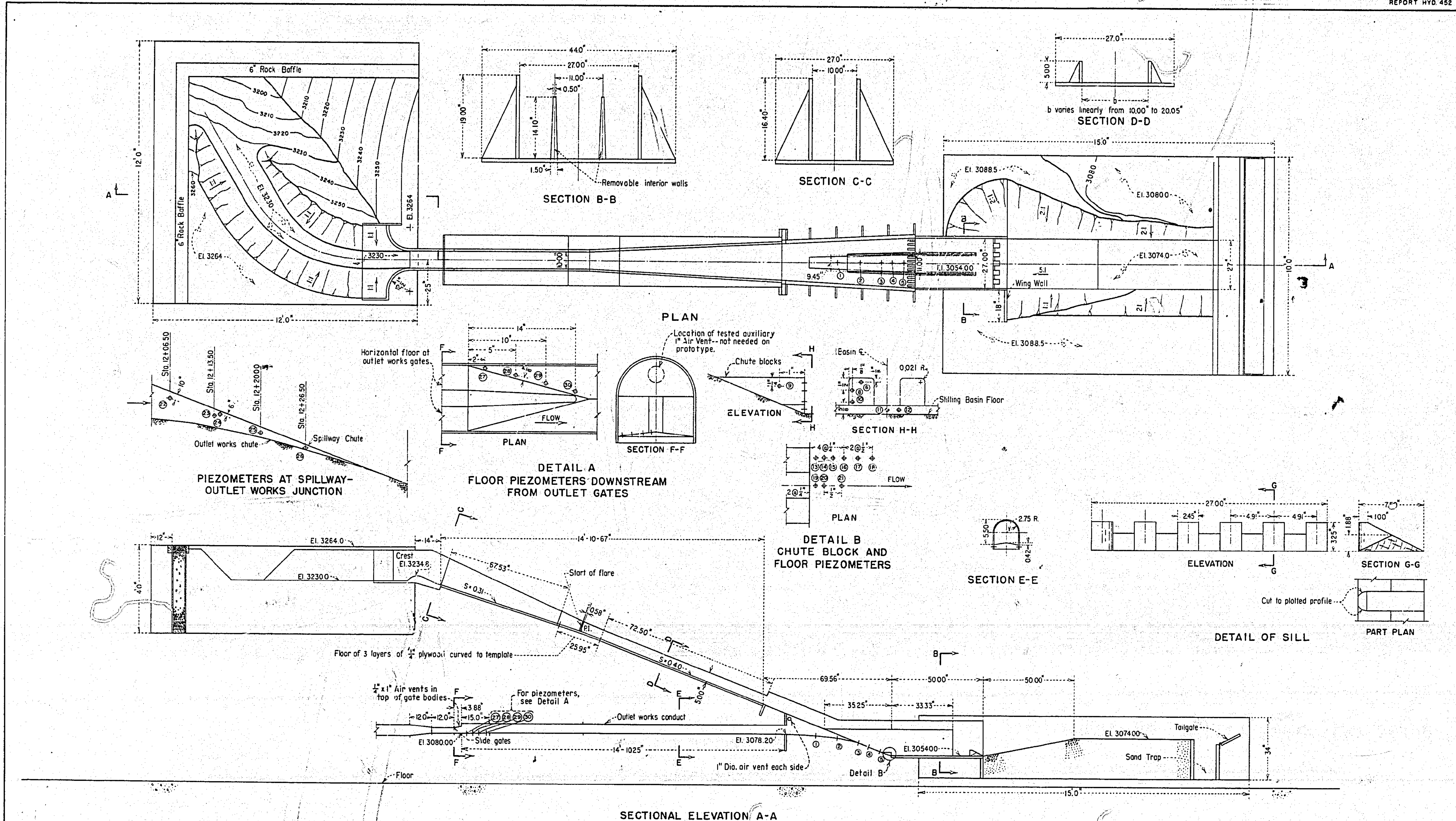


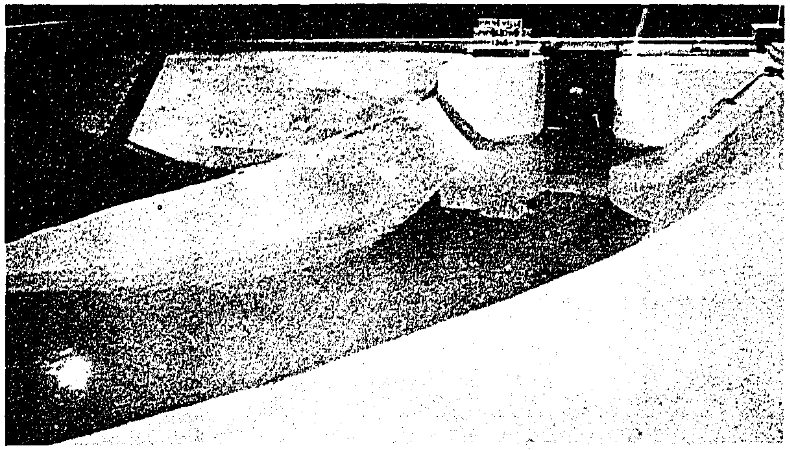
FIGURE 6
REPORT HYD. 452



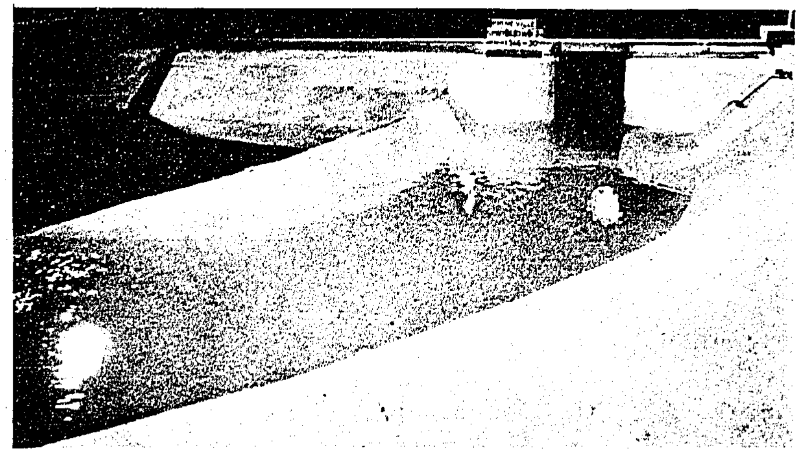

PLAN A-A
SCALE OF FEET
SECTION B-B
(SECOND STAGE CONCRETE NOT SHOWN)
SECTION B-B
GROUTING SYSTEM NOT SHOWN
DETAIL Y
SECTION C-C
NOTES
For general notes, see Dwg 40-D-5530.
Provide such temporary timbering and other protection as may be necessary to assure smooth unobstructed flow through the gate chamber during diversion.
All dimensions to rock are "A" line dimensions unless otherwise noted.
"B" Line is 3" outside of structural steel rib where supports are required and 3" outside the "A" line where supports are not required.
Structural steel supports not shown. Typical supports are shown on Dwg. 113-D-70.
Metal waterstops shall be placed at all construction joints.
Grout holes and drainage holes not shown, see Dwg 113-D-70
Electrical conduits and apparatus and gate control piping and apparatus not shown
REFERENCE DRAWINGS
OUTLET WORKS-PLAN, PROFILE AND SECTIONS 113-D-70
GATE CHAMBER AND ADIT-SHEET 2 OF 2 ..... 113-D-73
ACCESS SHAFT AND SHAFT HOUSE 113-D-74
20" AIR INLET PIPE 113-D-83
GATE CHAMBER VENTILATION SYSTEM 113-D-84
GATE CHAMBER VENTILATION SYSTEM-TYPICAL DETAILS 113-D-88
GATE HANGER ANCHOR 113-D-87
RESERVOIR LEVEL GAGE PIPING 113-D-129
UNITED STATES
DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
CROOKED RIVER PROJECT - OREGON
PRINEVILLE DAM
OUTLET WORKS
GATE CHAMBER AND ADIT
DENVER, COLORADO, APRIL 15, 1958
113-D-72



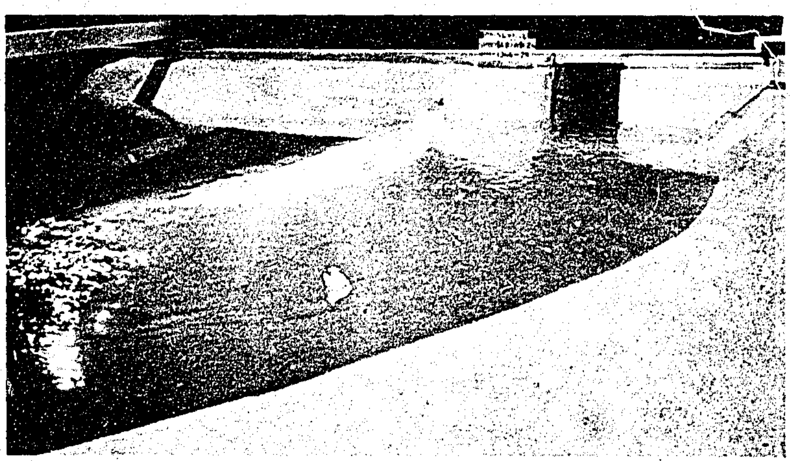
PRINEVILLE SPILLWAY AND OUTLET WORKS
1:24 SCALE MODEL



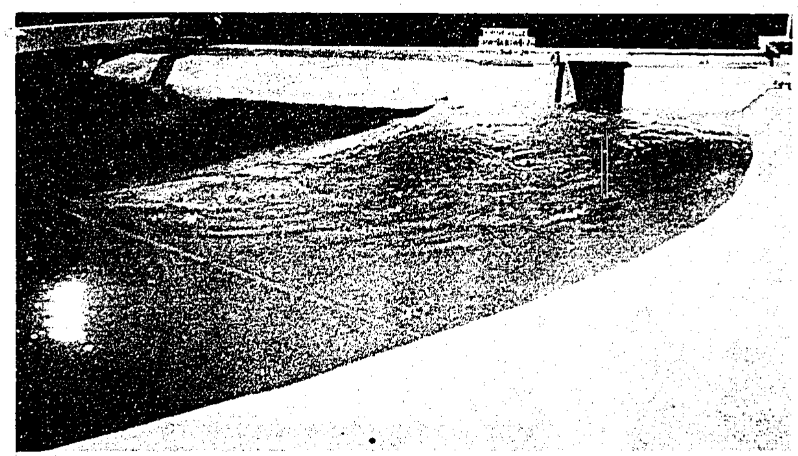
Q = 2,000 cfs Res. Elev. 3244.3



Q = 4,000 cfs Res. Elev. 3249.7

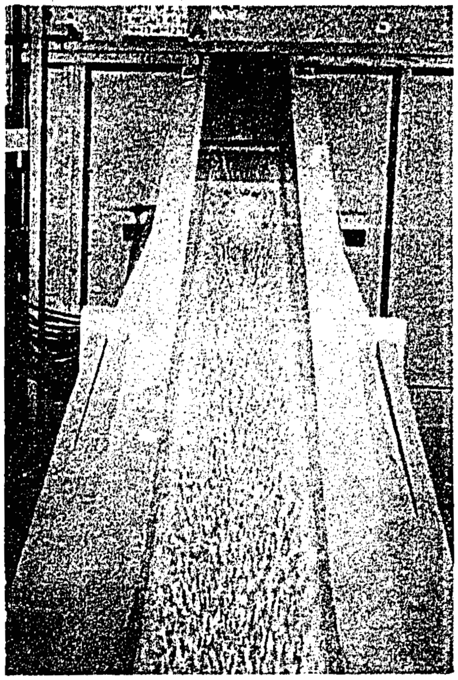


Q = 6,000 cfs Res. Elev. 3254.2

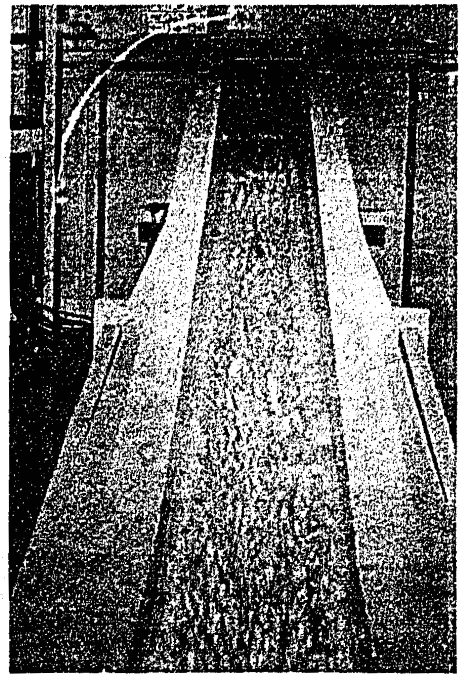


Q = 8,120 cfs (max.) Res. Elev. 3258.5

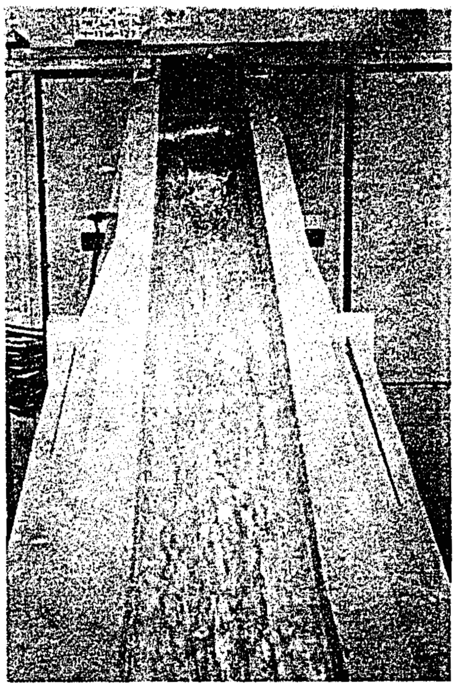
PRINEVILLE SPILLWAY AND OUTLET WORKS
Flow in Reservoir and Spillway Approach Channel
1:24 Scale Model



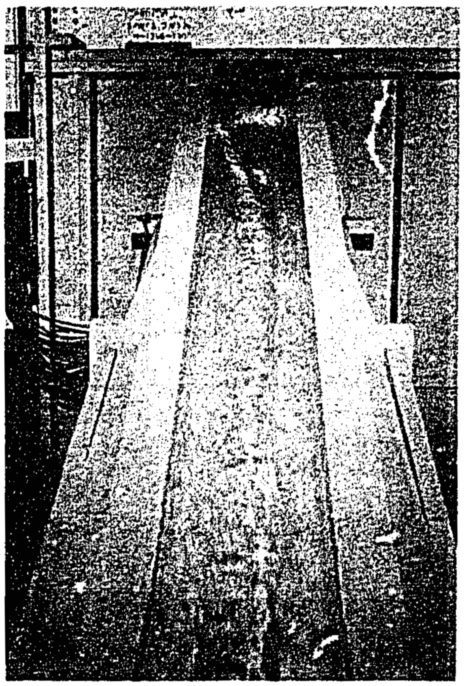
Q = 2,000 cfs



Q = 4,000 cfs

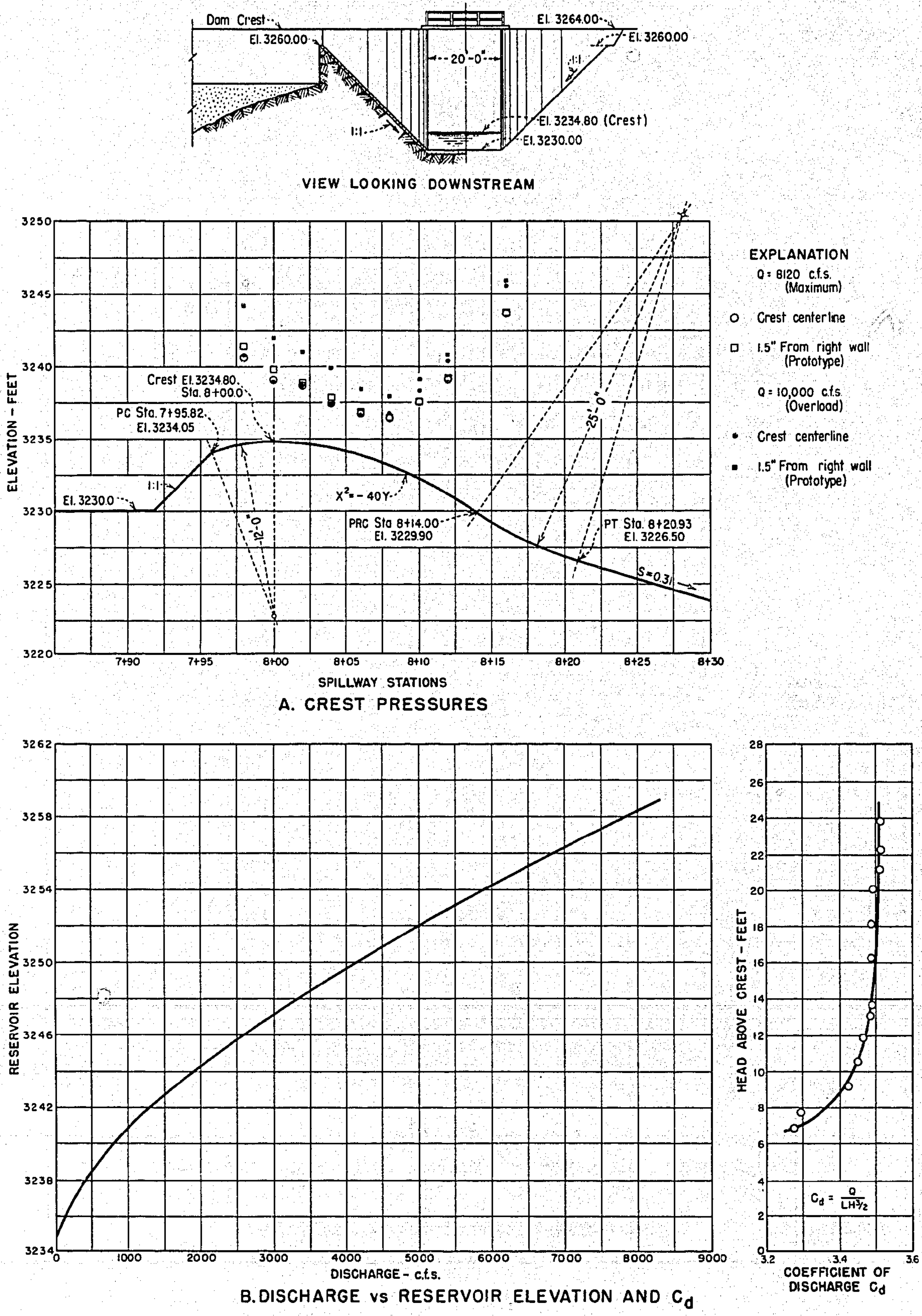


Q = 6,000 cfs



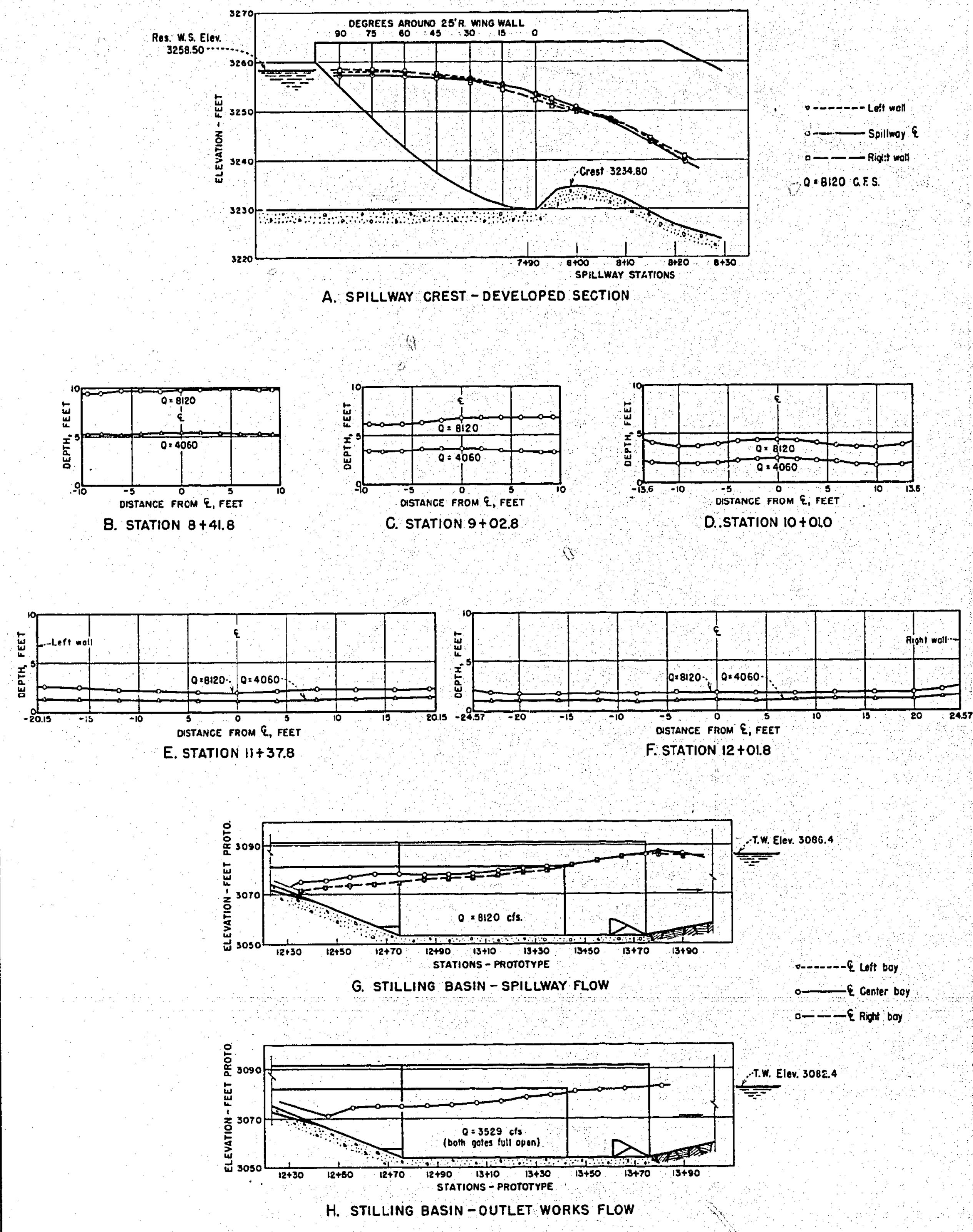
Q = 8,120 cfs (max.)

PRINEVILLE SPILLWAY AND OUTLET WORKS
Flow At Crest and on Spillway Chute
1:24 Scale Model



PRINEVILLE SPILLWAY AND OUTLET WORKS
SPILLWAY DISCHARGE CURVES AND CREST PRESSURES
1:24 SCALE MODEL

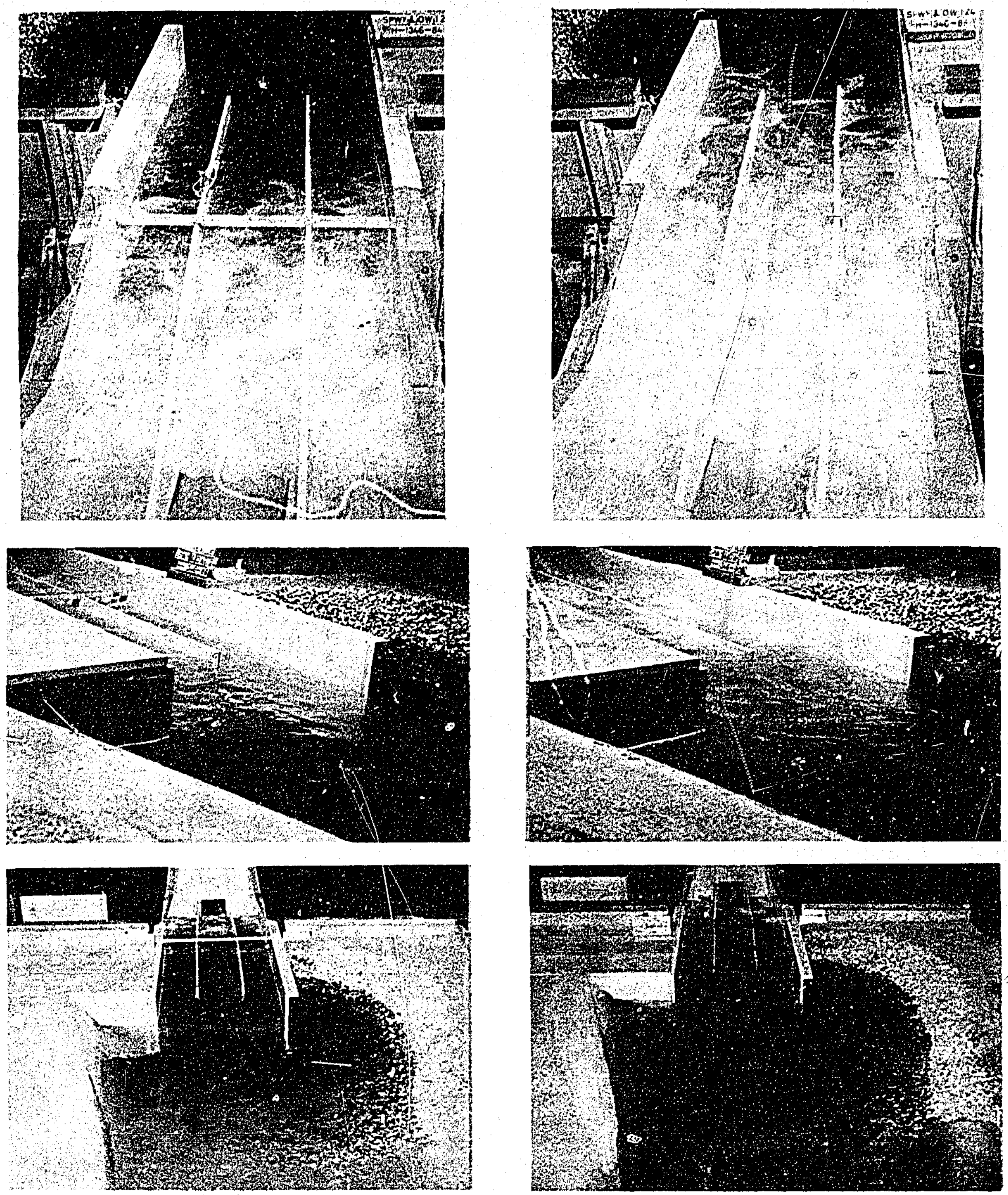
598



PRINEVILLE SPILLWAY AND OUTLET WORKS

SPILLWAY WATER SURFACE PROFILES

1:24 SCALE MODEL

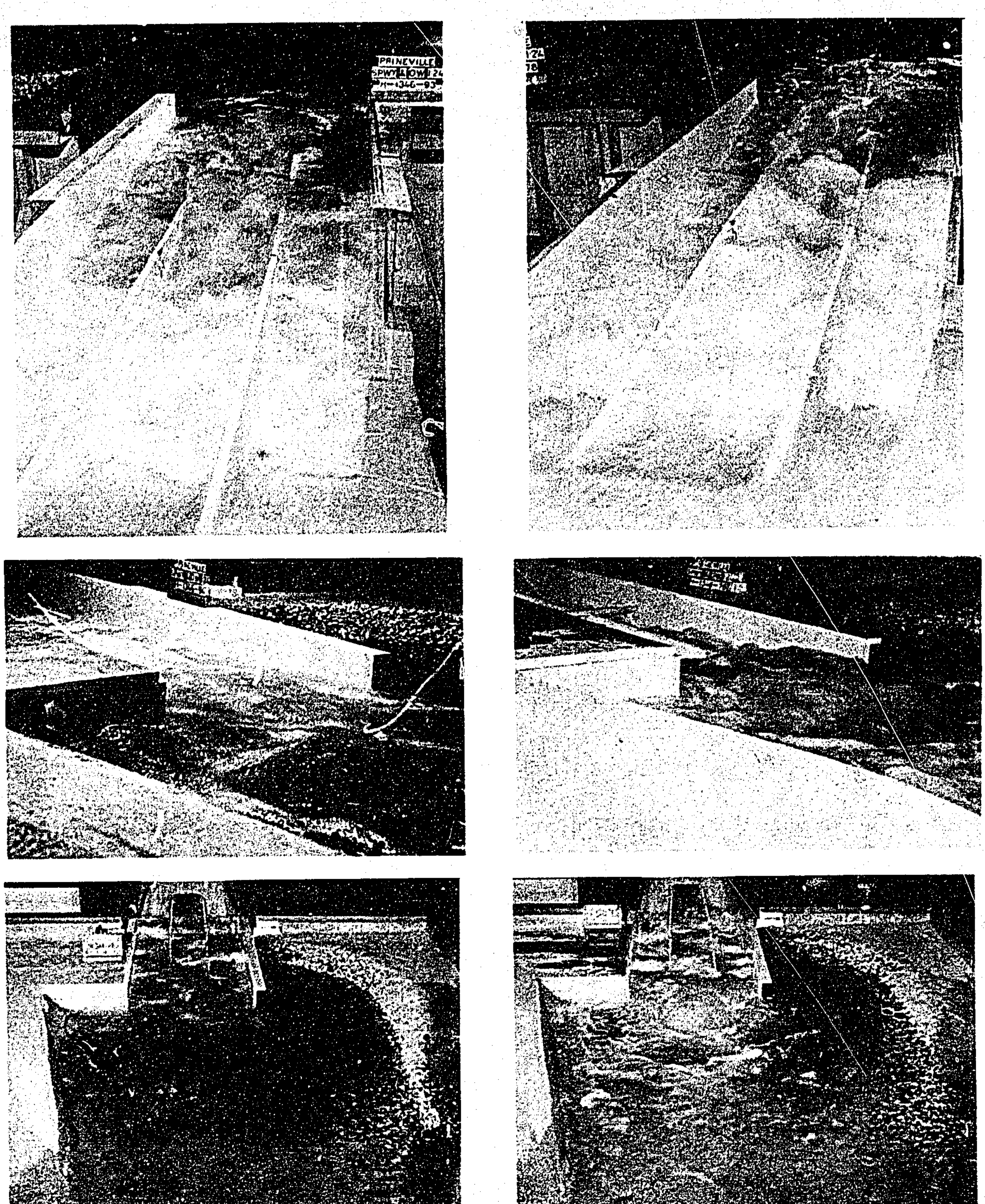


Q = 1,000 cfs TW = 3078.7

Q = 3,000 cfs TW = 3081.8

PRINEVILLE SPILLWAY AND OUTLET WORKS
Low Spillway Flows in Recommended Stilling Basin
1:24 Scale Model

Figure 14
Report Hyd 452



Q = 6,000 cfs TW = 3084.7

Q = 8,120 cfs (max.) TW = 3086.4

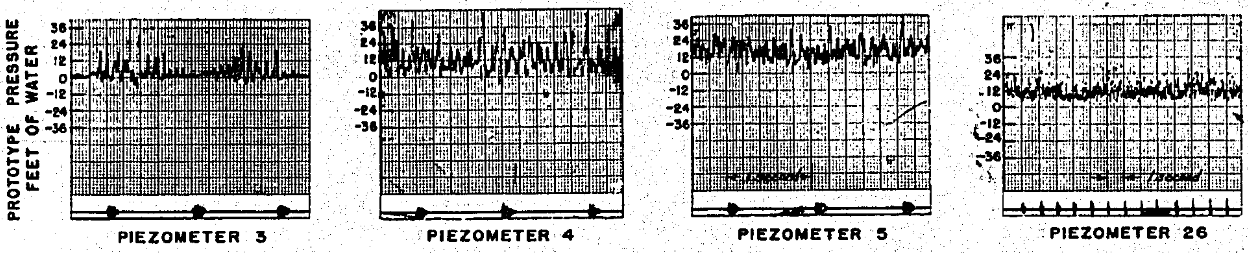
PRINEVILLE SPILLWAY AND OUTLET WORKS
High Spillway Flows in Recommended Stilling Basin
1:24 Scale Model

TYPE OF FLOW		PIEZOMETER NUMBER																									
		JUNCTION FLOOR					CHUTE BLOCK					STEP		FLOOR BELOW BLOCKS									JUNCTION SIDE				
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
SPILLWAY	Q = 8120 * TW = 3086.4	–	–	4.1	12.0	18.7	8.4	–	19.7	8.6	7.9	12.9	12.7	–	–	–	–	–	31.7	–	–	–	–	0	0	0.2	10.8
	Q = 8120 † TW = 3081.2	–	–	0.2	7.2	15.4	1.4	–	0.5	20.2	-1.9	7.9	7.7	–	–	–	–	–	29.8	–	–	–	–	0	0	0.2	9.1
OUTLET WORKS	Q = 4060 * TW = 3083.0	–	1.2	0.5	2.4	9.8	4.8	–	3.4	12.2	2.4	7.4	7.2	8.7	8.3	6.0	–	11.8	20.9	8.6	9.2	7.5	–	0	0.2	0.2	0
	Q = 3529 * TW = 3082.5	0.2	1.0	0.5	6.0	16.3	5.5	–	2.4 5.0	9.6 13.0	-0.5 +2.4	11.0	10.3	–	–	–	–	–	20.8	–	–	–	–	0	0.2	0.2	0.7
	Q = 3529 † TW = 3080.0	0.2	1.0	0.5	3.6	14.6	-0.5 +3.1	–	-1.0 +1.0	8.2 10.1	-4.3 +0.2	7.2	6.7	–	–	–	–	–	19.0	–	–	–	–	0	0.2	0.2	0.5

* Normal Tailwater
† Low Tailwater

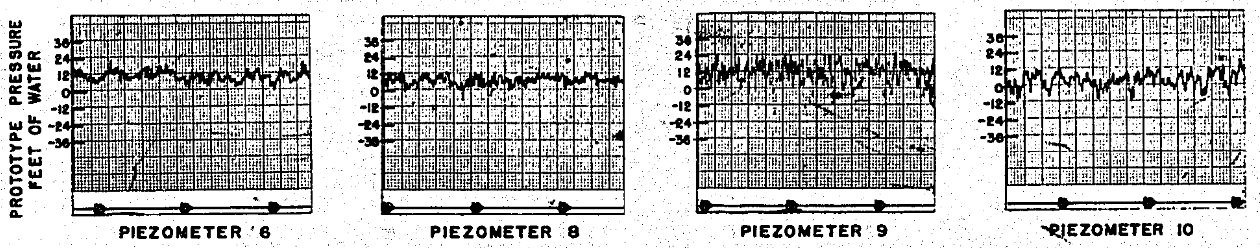
A. WATER MANOMETER PRESSURES

(PIEZOMETERS SHOWN ON FIGURE 8)



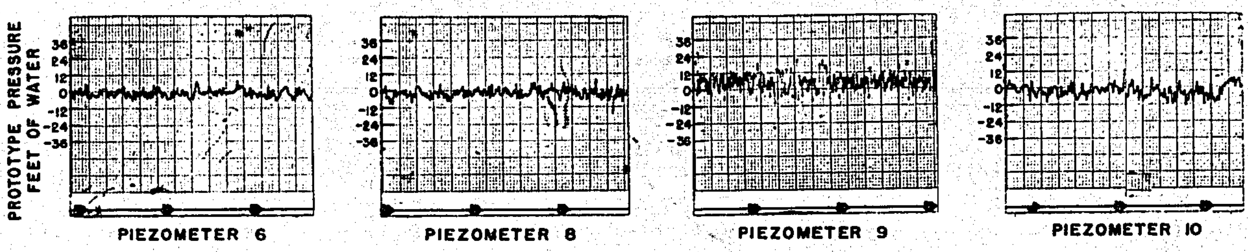
B PRESSURE CELL PRESSURES. SPILLWAY FLOW

Q = 8120 C.F.S. TW = 3086.4 (NORMAL)



C. PRESSURE CELL PRESSURES. OUTLET WORKS FLOW

Q = 3529 C.F.S. TW = 3082.45 (NORMAL)



D. PRESSURE CELL PRESSURES. OUTLET WORKS FLOW

Q = 3529 C.F.S. TW = 3080.00 (LOW)

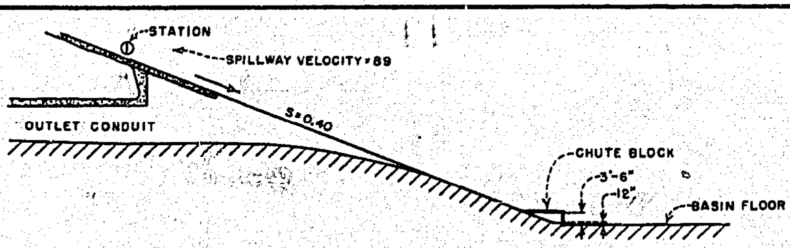
PRINEVILLE SPILLWAY AND OUTLET WORKS

PRESSURES AND PRESSURE VARIATIONS IN STILLING BASIN

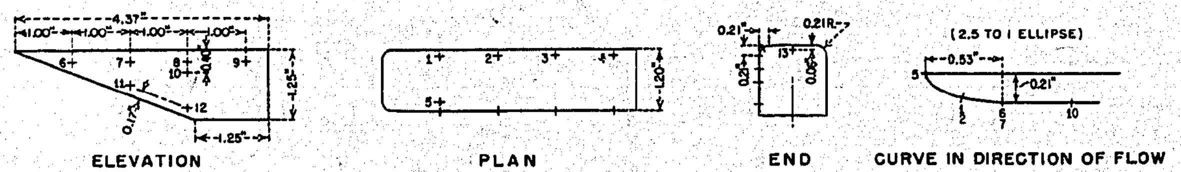
INITIAL STUDIES

1:24 SCALE MODEL

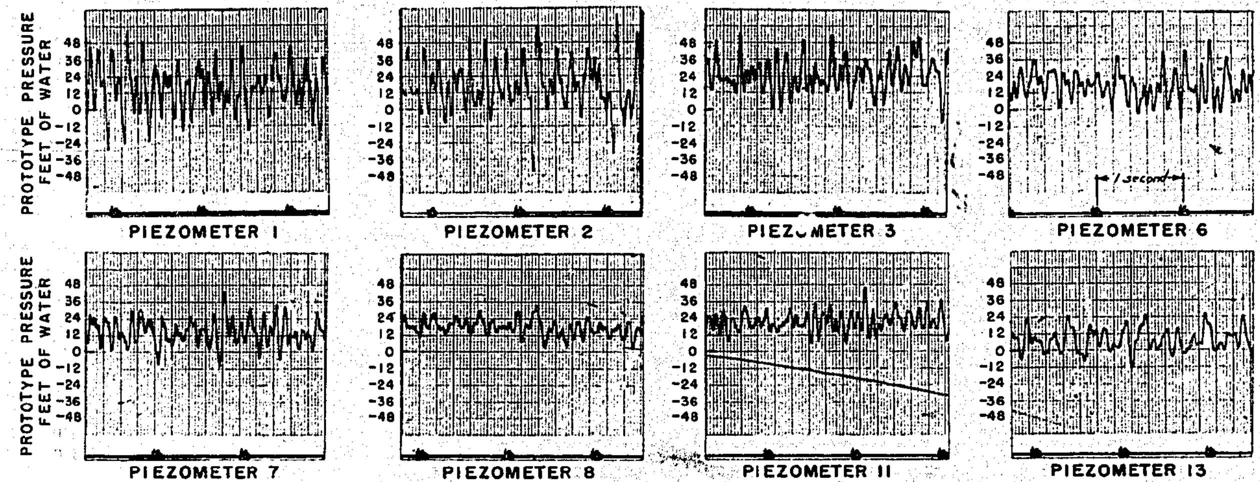
FIGURE 16
REPORT HYD. 452



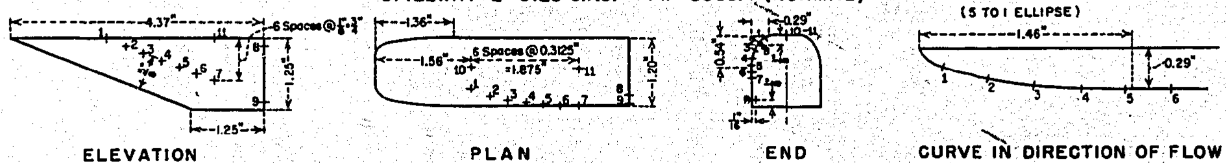
A. CHUTE BLOCK INSTALLATION



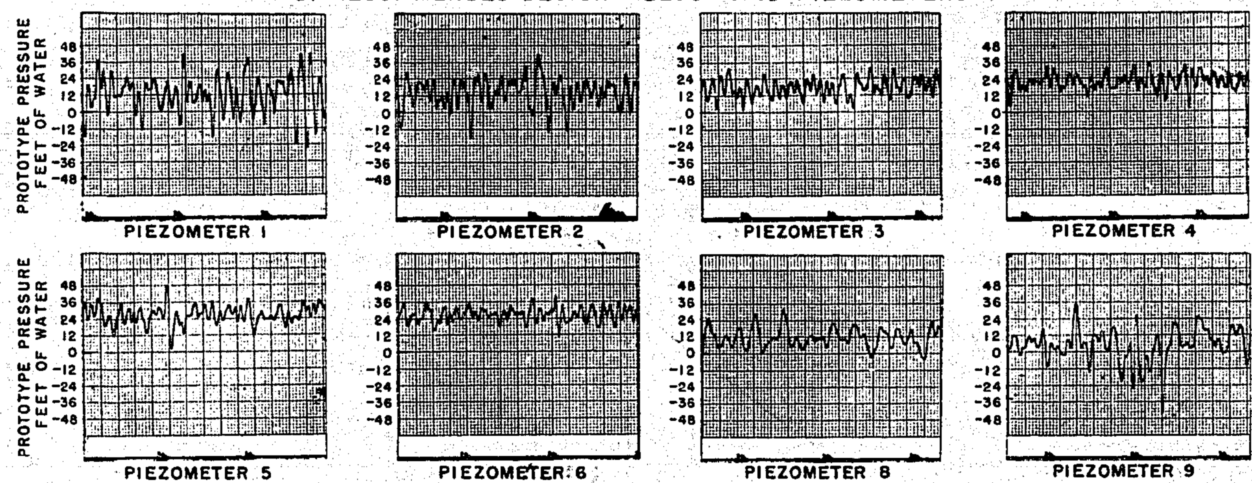
B. INITIAL DESIGN — BLOCK AND PIEZOMETERS



C. INITIAL DESIGN — PIEZOMETER PRESSURES
SPILLWAY Q = 8120 C.F.S. TW = 3086.4 (NORMAL)



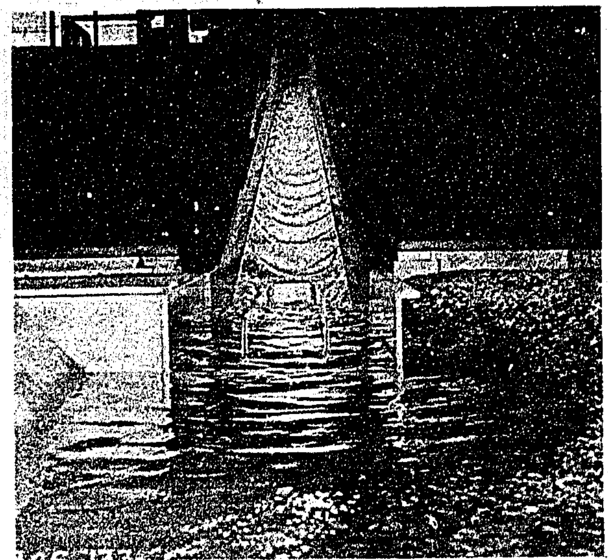
D. RECOMMENDED DESIGN — BLOCK AND PIEZOMETERS



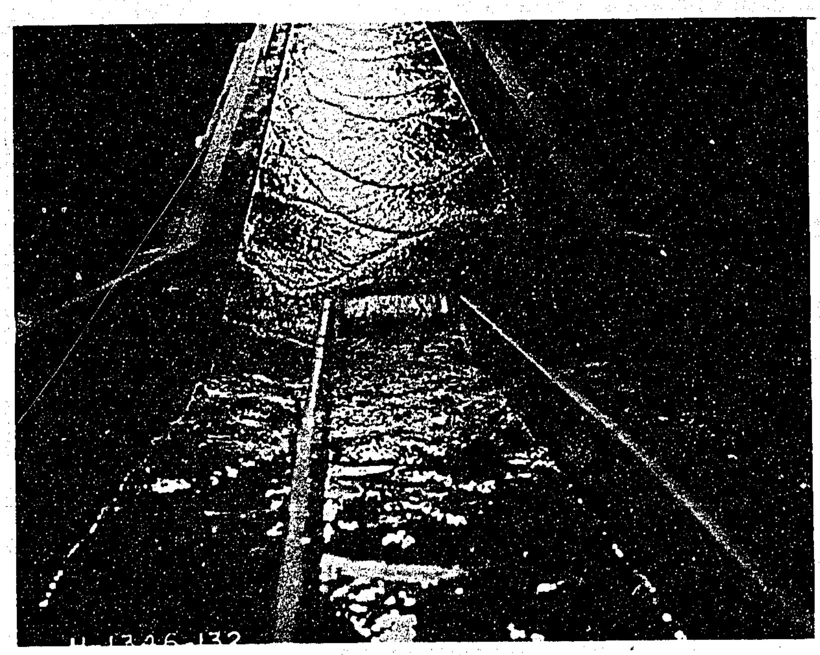
E. RECOMMENDED DESIGN — PIEZOMETER PRESSURES
SPILLWAY Q = 8120 C.F.S TW = 3086.4 (NORMAL)

PRINEVILLE SPILLWAY AND OUTLET WORKS
CHUTE BLOCK SHAPES AND PRESSURE VARIATIONS
DETAILED STUDIES
1:24 SCALE MODEL

598

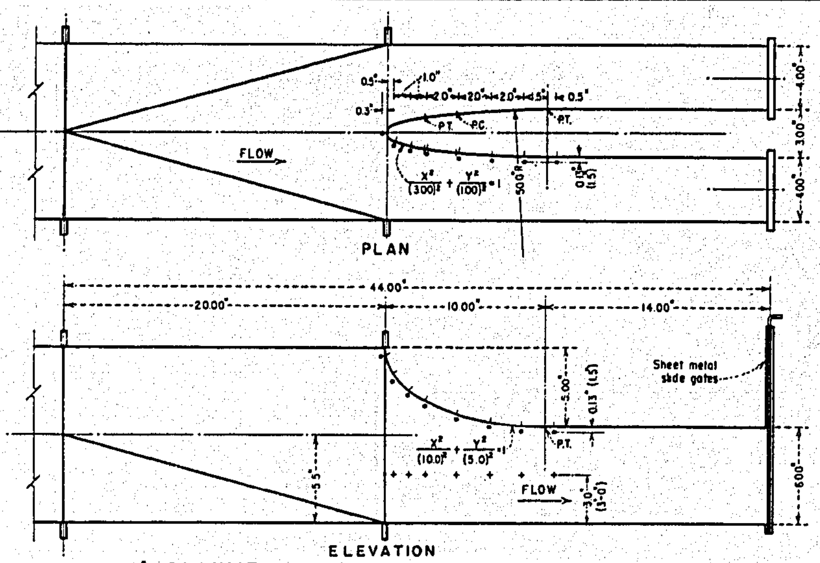


A. The smooth sheet of water at the crest roughens and develops into progressively larger roll waves

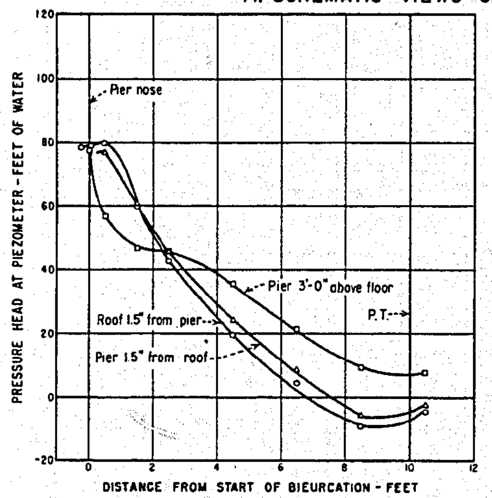


B. The roll waves strike the stilling pool and cause considerable splashing and wave action

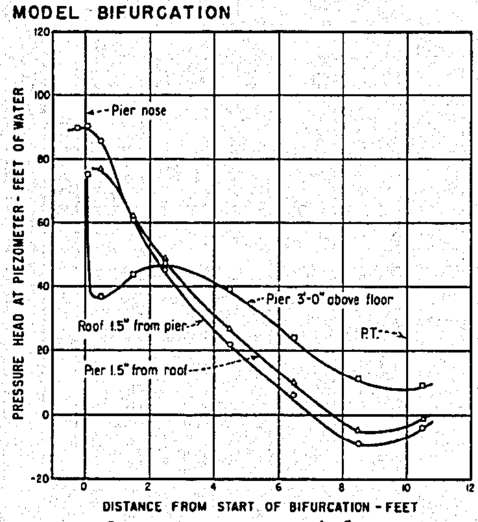
PRINEVILLE SPILLWAY AND OUTLET WORKS
Roll Waves in Spillway
Q = 300 cfs
1:24 Scale Model



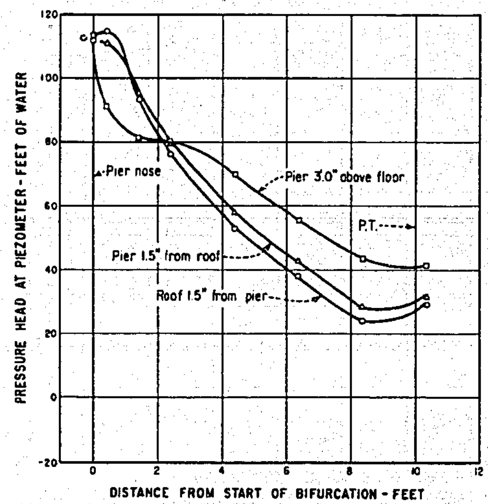
A. SCHEMATIC VIEWS OF MODEL BIFURCATION



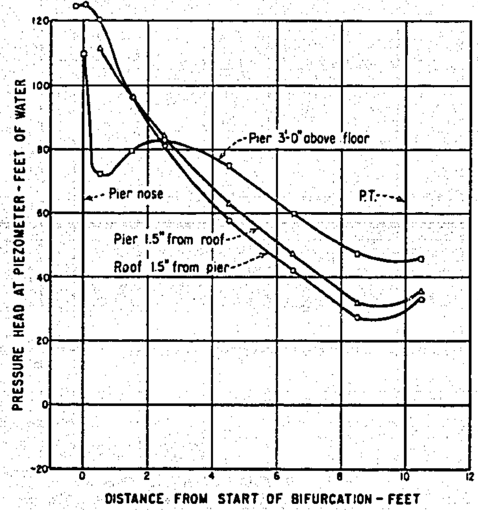
B. BOTH GATES 6'-0" OPEN



C. ONE GATE ONLY 6'-0" OPEN



D. BOTH GATES 5'-6" OPEN

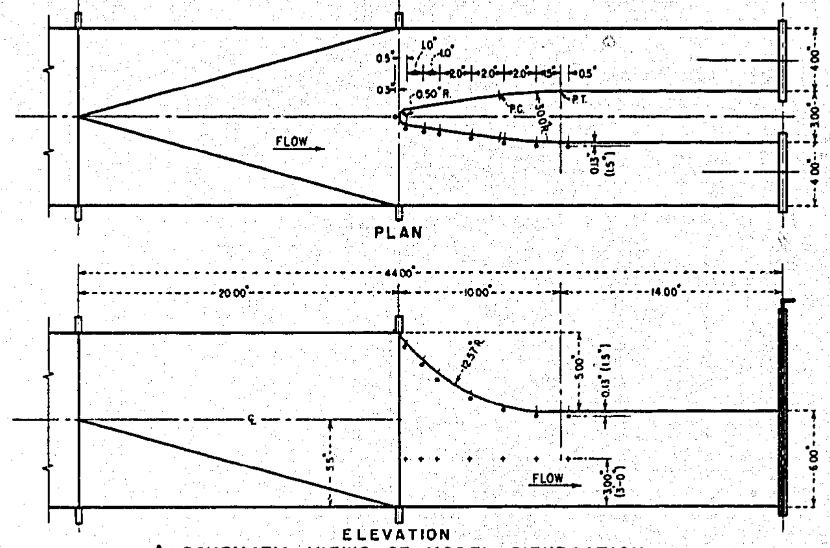


E. ONE GATE ONLY 5'-6" OPEN

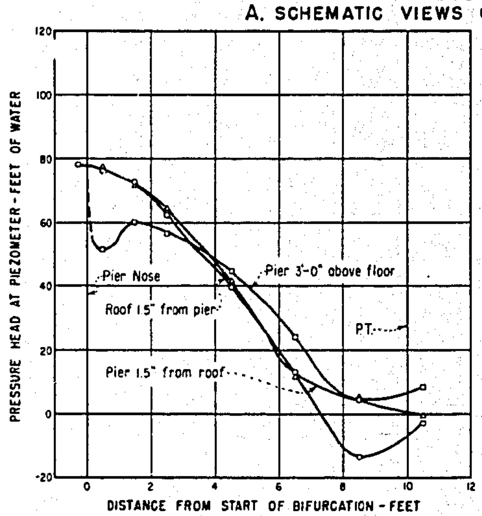
PRINEVILLE SPILLWAY AND OUTLET WORKS

PRESSURES IN BIFURCATION AT OUTLET GATES USING ELLIPTICALLY-SHAPED PIER SURFACES

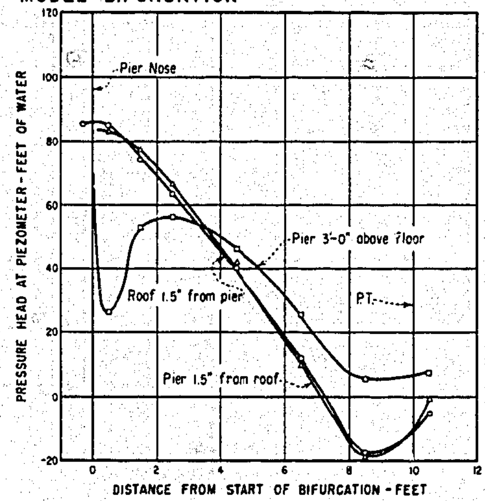
1:12 SCALE, AIR MODEL



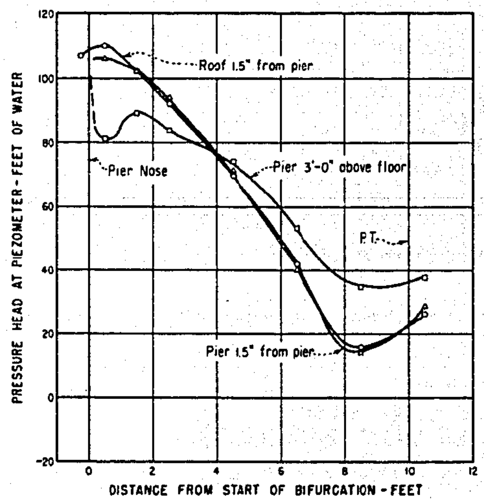
A. SCHEMATIC VIEWS OF MODEL BIFURCATION



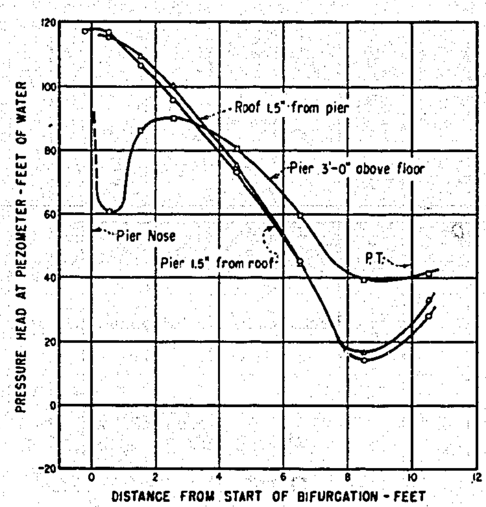
B. BOTH GATES 6'-0" OPEN



C. ONE GATE ONLY 6'-0" OPEN



D. BOTH GATES 5'-6" OPEN

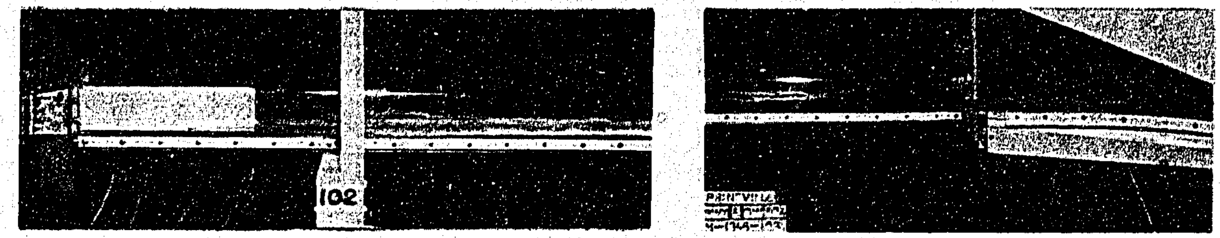


E. ONE GATE ONLY 5'-6" OPEN

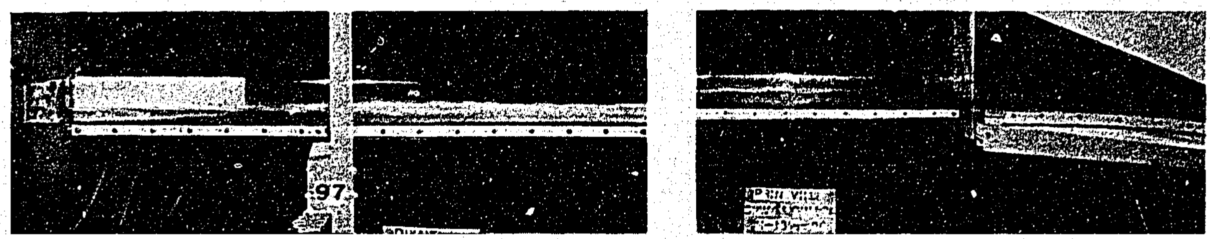
PRINEVILLE SPILLWAY AND OUTLET WORKS

PRESSURES IN BIFURCATION AT OUTLET GATES USING CIRCULARLY-SHAPED PIER SURFACES

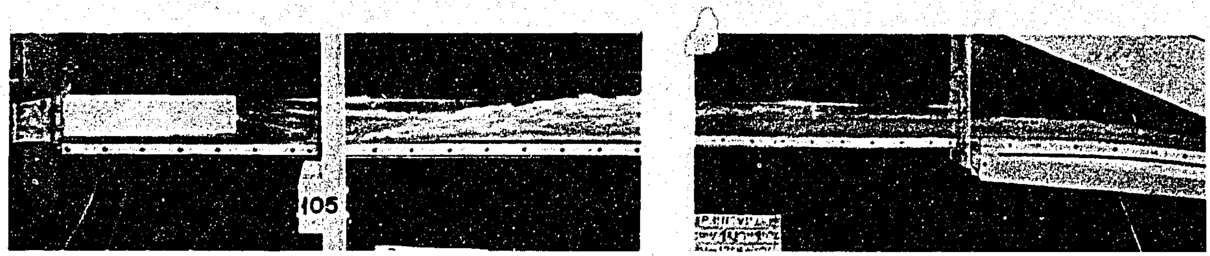
1:12 SCALE, AIR MODEL



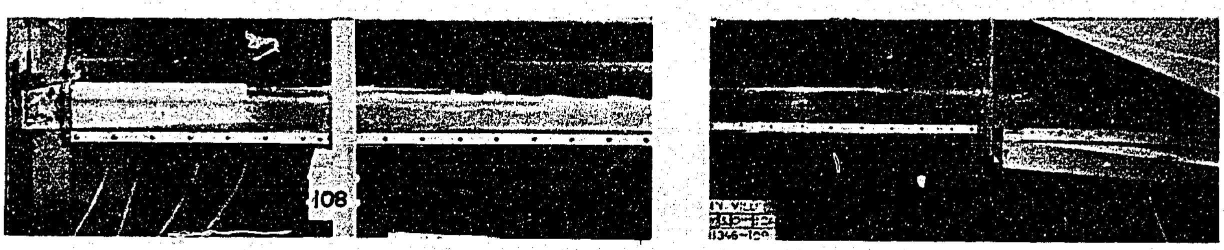
A. Q = 800 cfs Left gate only; 3'-0"



B. Q = 1,600 cfs Both gates 3'-0" open



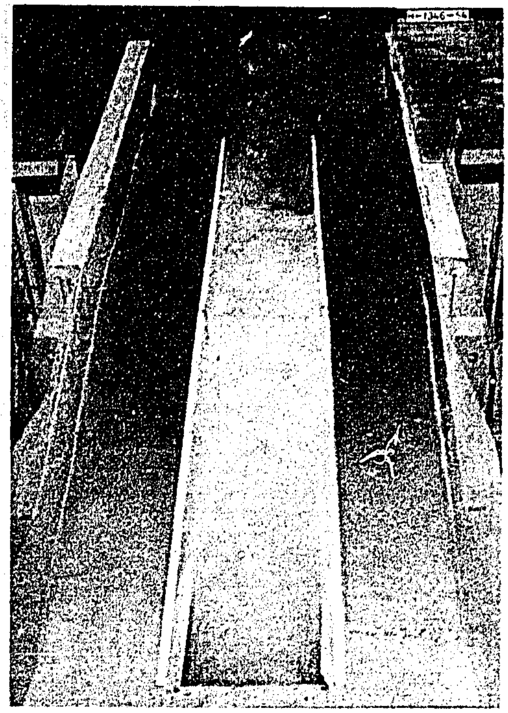
C. Q = 1,800 cfs Left gate only; open 5'-6"

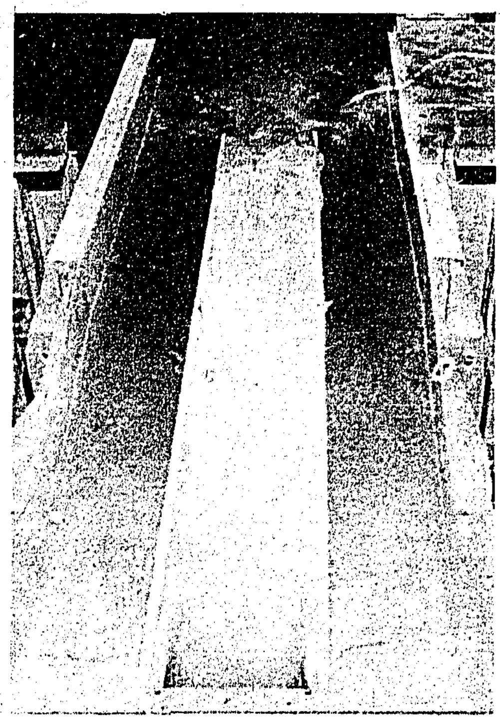


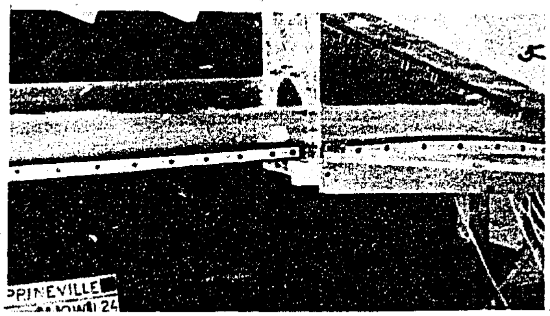
D. Q = 3,529 cfs Both gates open 5'-6"

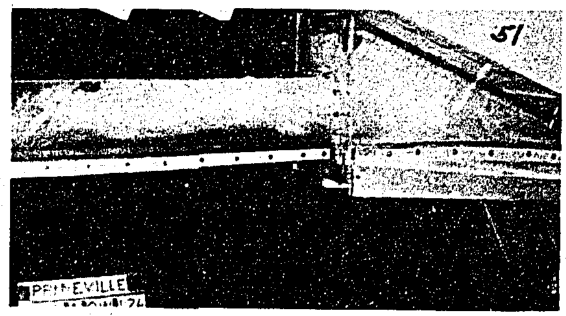
PRINEVILLE SPILLWAY AND OUTLET WORKS
Outlet Flows Through Gates, Tunnel, and
Spillway Junction Res. Elev. 3234.8
1:24 Scale Model

Figure 21
Report Hyd 452





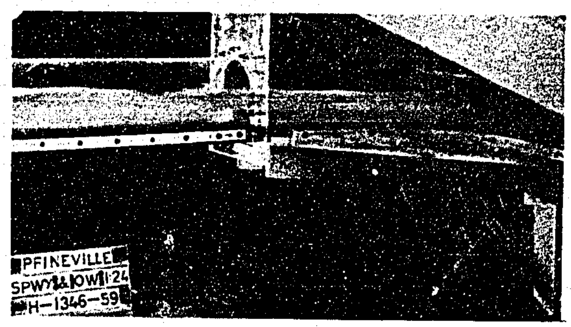


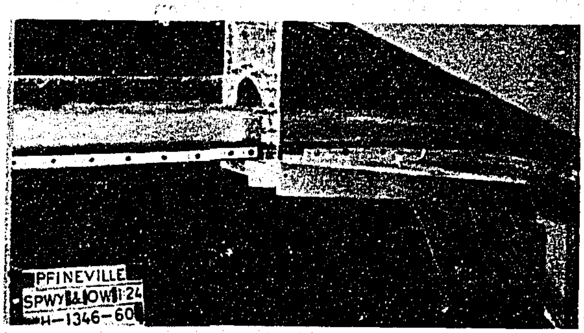


Q = 4,080 cfs Flow not backed up by cover

Q = 4,080 cfs Flow backed up by cover

A. Initial Design - Cover Slab End of Station 11+98.75



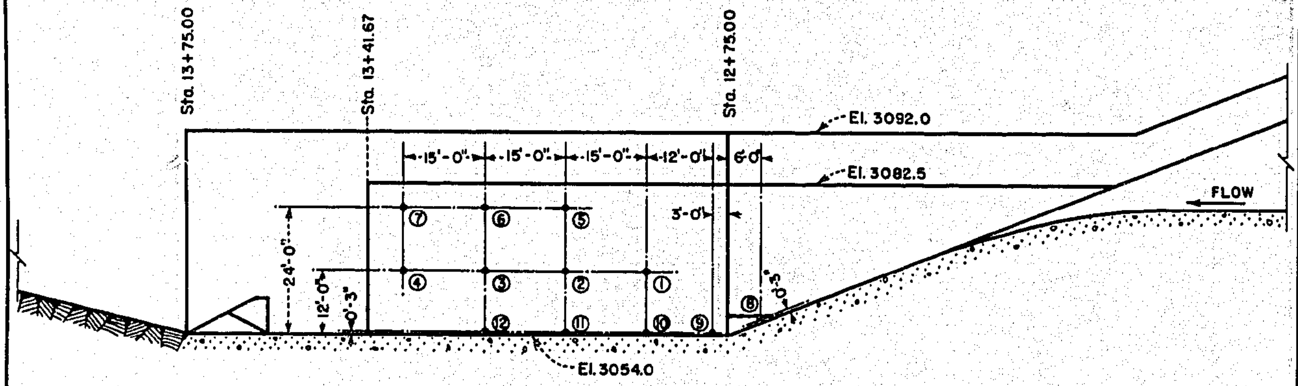


Q = 4,080 cfs, outlets only

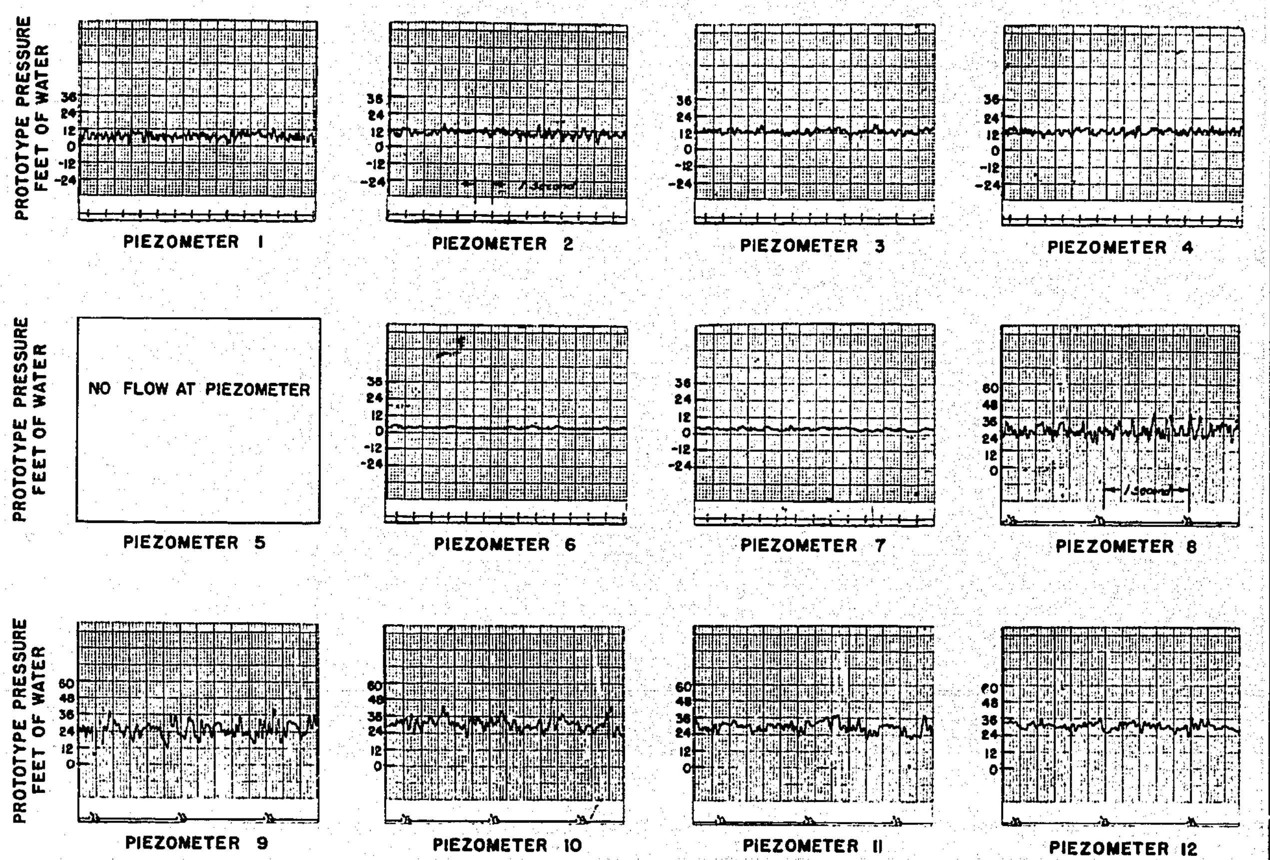
Q = 4.080 cfs, outlets, and 2,480 cfs, spillway

B. Recommended Design - Cover Slab End at Station 11+95.96

PRINEVILLE SPILLWAY AND OUTLET WORKS
Outlet Works Flows At Spillway Junction
Res. Elev. 3234.8
1:24 Scale Model



A LOCATION OF PIEZOMETERS



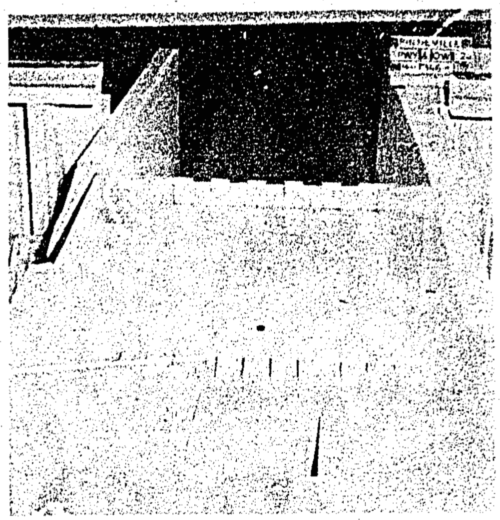
B PRESSURE CELL PRESSURES

Q = 3529 C.F.S. TW = 3082.45

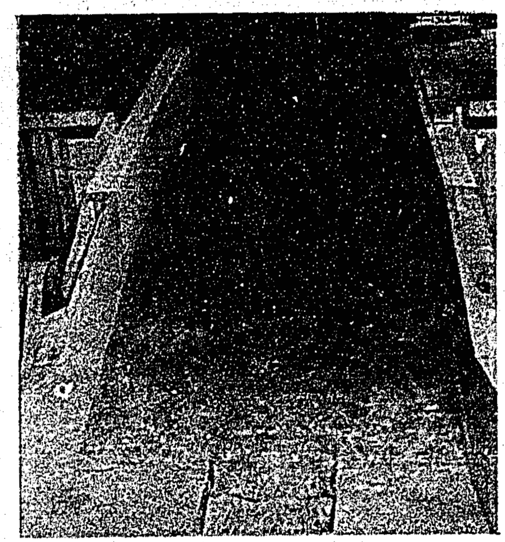
PRINEVILLE SPILLWAY AND OUTLET WORKS

PRESSURE VARIATIONS ON STILLING BASIN DIVIDING WALLS

1:24 SCALE MODEL



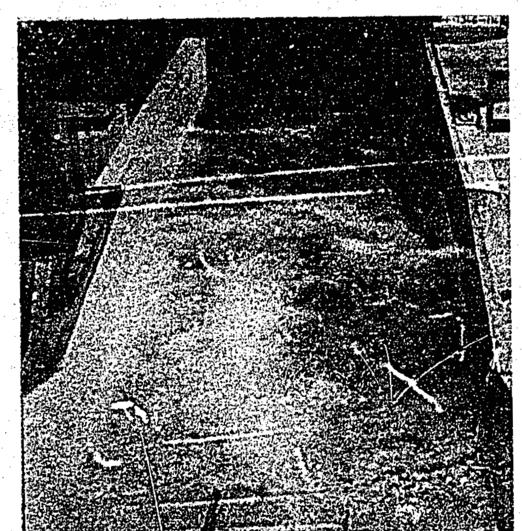
Basin Without Walls



Q = 800 cfs Both Gates 5'-6" open

Q = 800 cfs, Gates throttled, full res.

Q = 1,600 cfs Both gates 5'-6" open



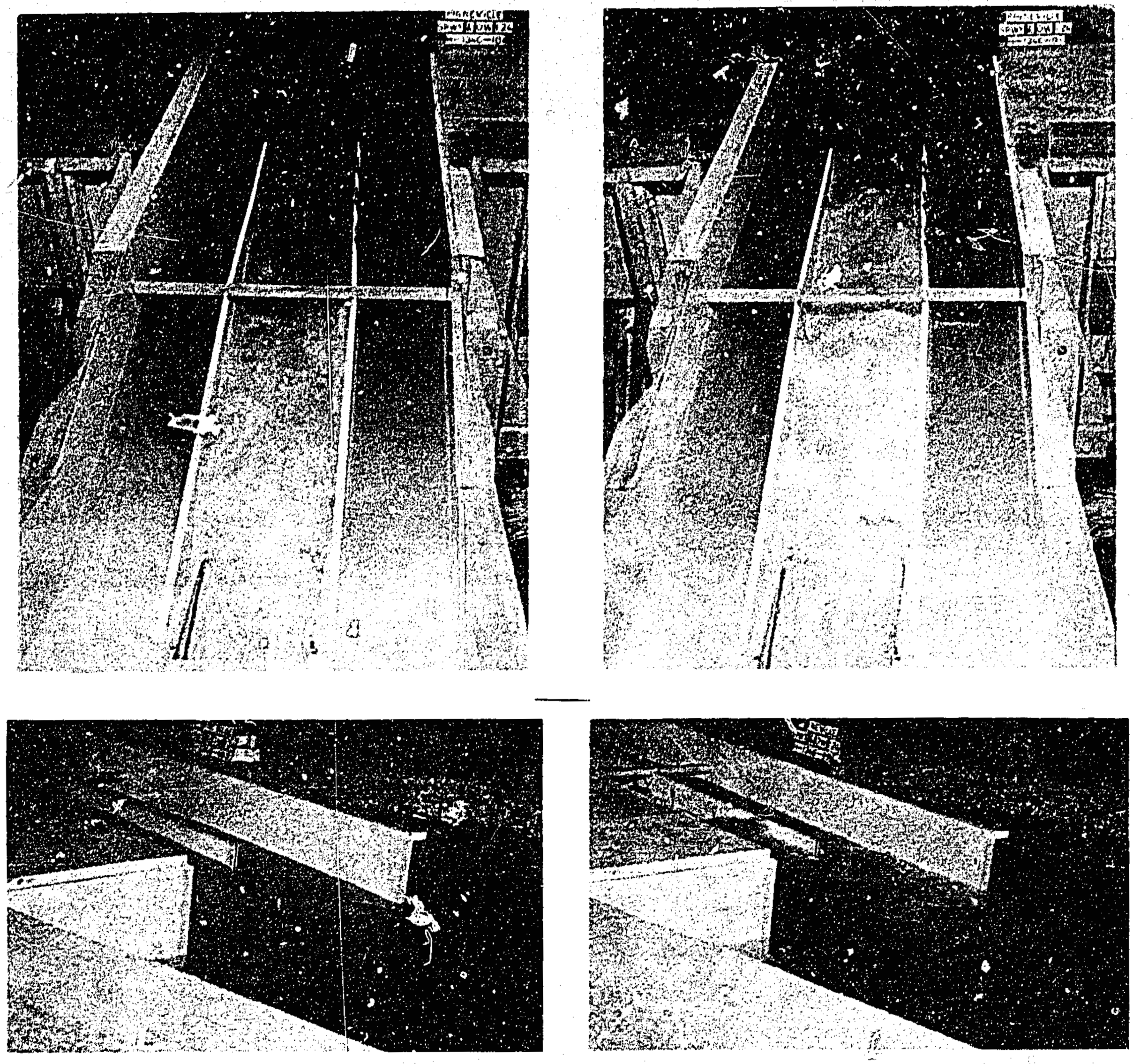
Q = 1,600 cfs, Gates throttled, full res.

Q = 3,529 cfs Both gates 5'-6" open

PRINEVILLE SPILLWAY AND OUTLET WORKS
Outlet Flows in Stilling Basin Without Dividing Walls
1:24 Scale Model

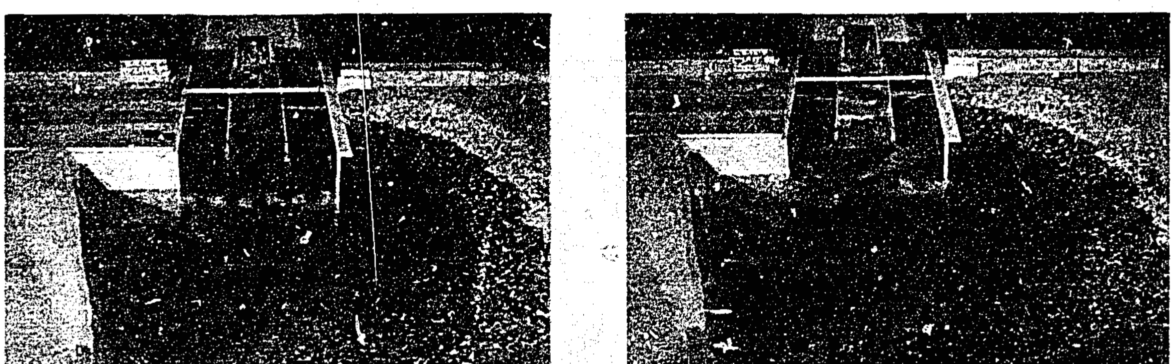
Figure 23
Report Hyd 452

Figure 24
Report Hyd 452



Q = 800 cfs   Left gate only; open 5'-6"

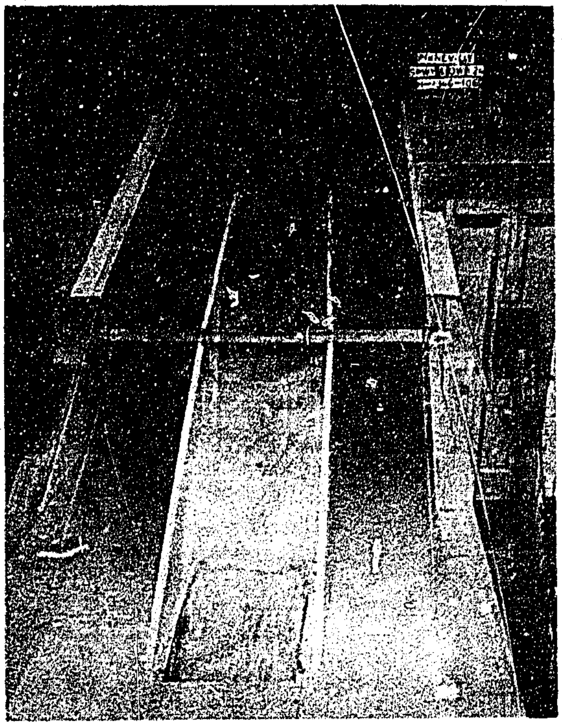
Q = 1,600 cfs   Both gates open 5'-6"

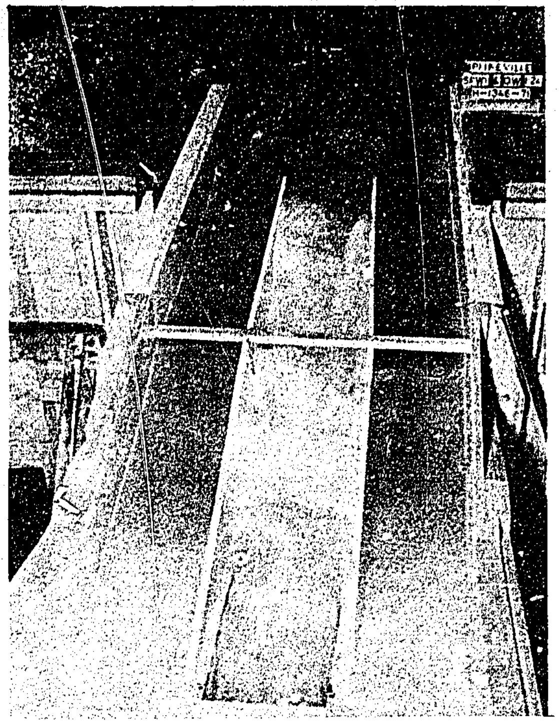


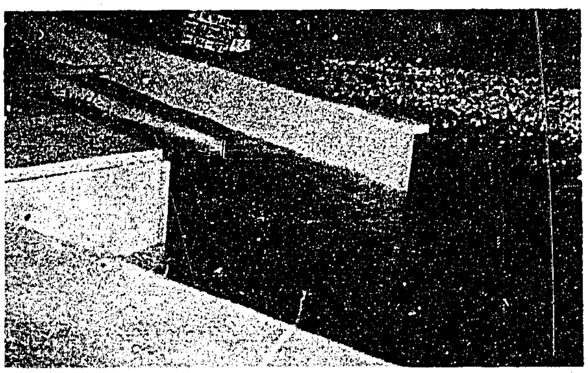
Q = 1,600 cfs   Both gates open 5'-6"
Reservoir Elev. 3122.5

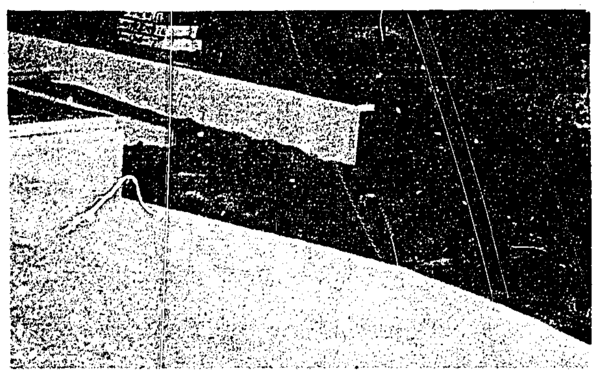
Q = 1,600 cfs   Both gates throttled
Reservoir Elev. 3234.8 (crest)

PRINEVILLE SPILLWAY AND OUTLET WORKS
Low Outlet Flows in Recommended Stilling Basin
1:24 Scale Model



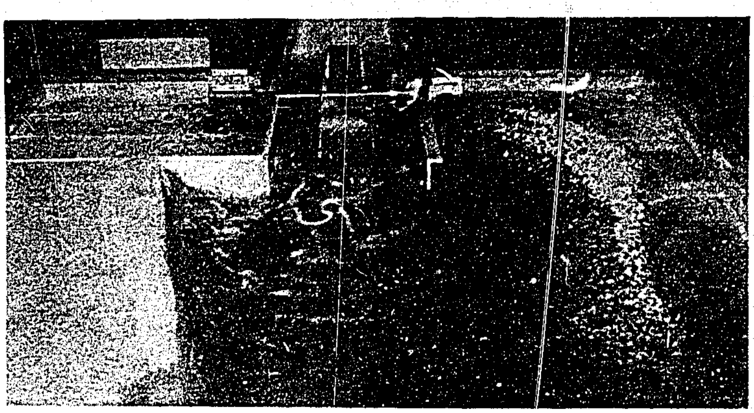






Q = 1,800 cfs   Left Gate only; open 5'-6"

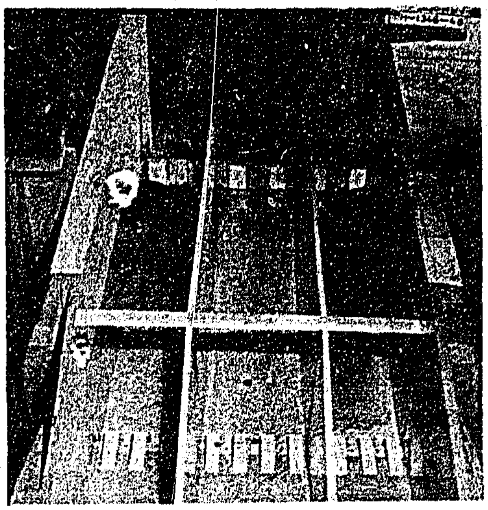
Q = 3,529 cfs   Both gates 5'-6" open



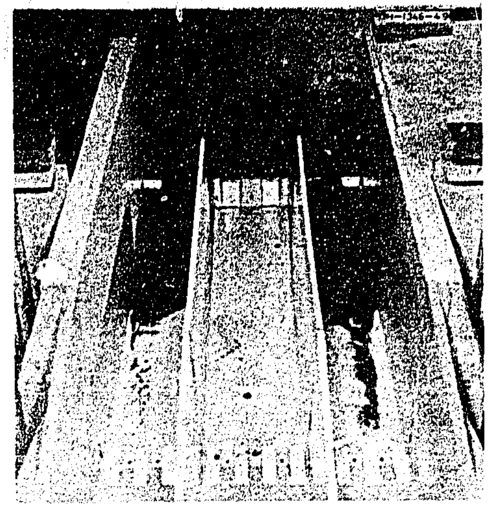
Q = 3529 cfs   Both Gates open 5'-6"

PRINEVILLE SPILLWAY AND OUTLET WORKS
High Outlet Flows in Recommended Stilling Basin
1:24 Scale Model

Figure 26
Report Hyd 452

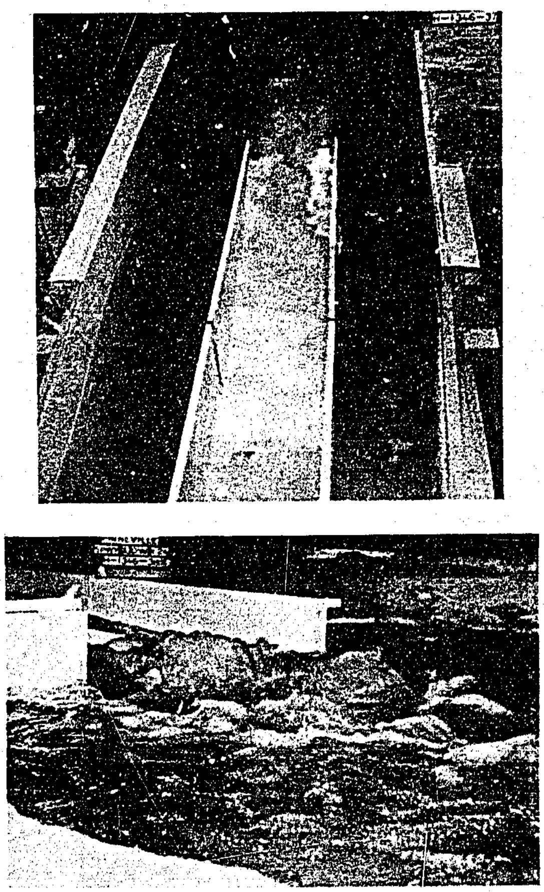


A. Sand in basin after 2 hrs model operation, Q = 4,080 cfs, Initial Walls

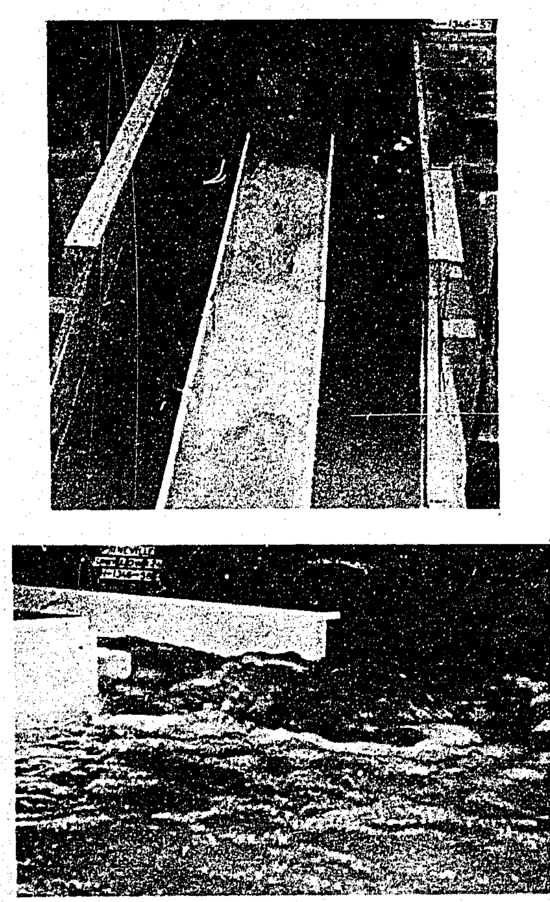


B. Sand in basin after 2 hrs. model operation, Q = 4,080 cfs, Walls 18 feet high extended to end of basin

(No deposits with 28.5 foot-high walls extended to end of basin)

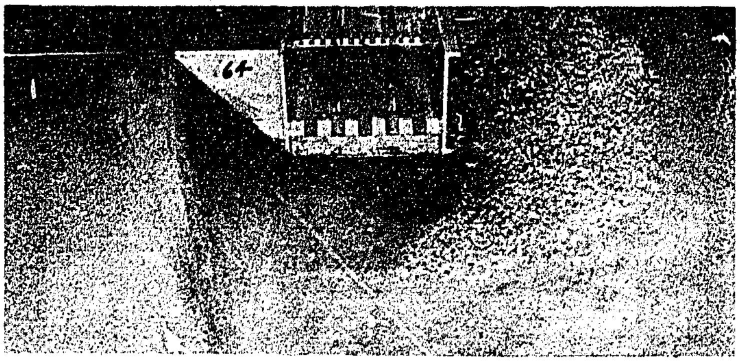


C. Walls 28.5 feet high extended to end of basin. Q = 4,080 cfs



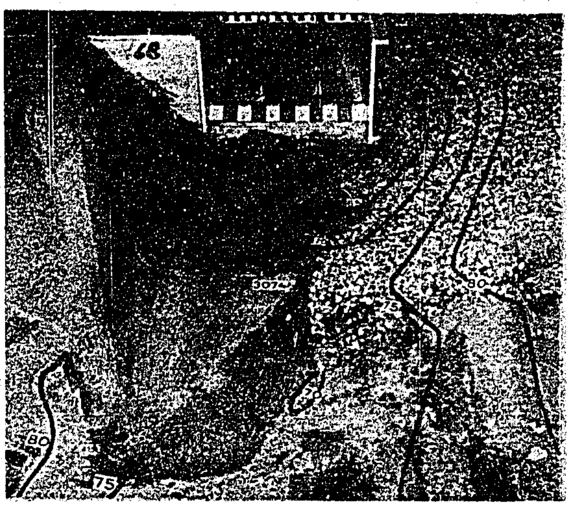
D. Walls 18 feet high extended to end of basin. Q = 4,080 cfs

PRINEVILLE SPILLWAY AND OUTLET WORKS
Flow Conditions and Sand Deposits in Stilling Basin
With and Without Dividing Walls
1:24 Scale Model

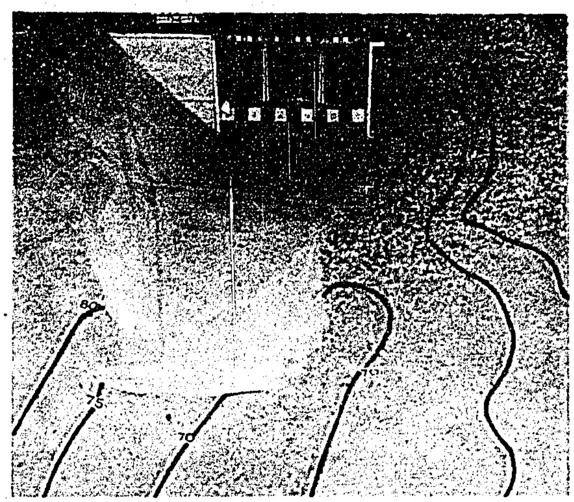


A. Channel to river with rock & 2:1 riprapped slopes

B. Flow Conditions with Recommended Walls. Q = 3,529 cfs



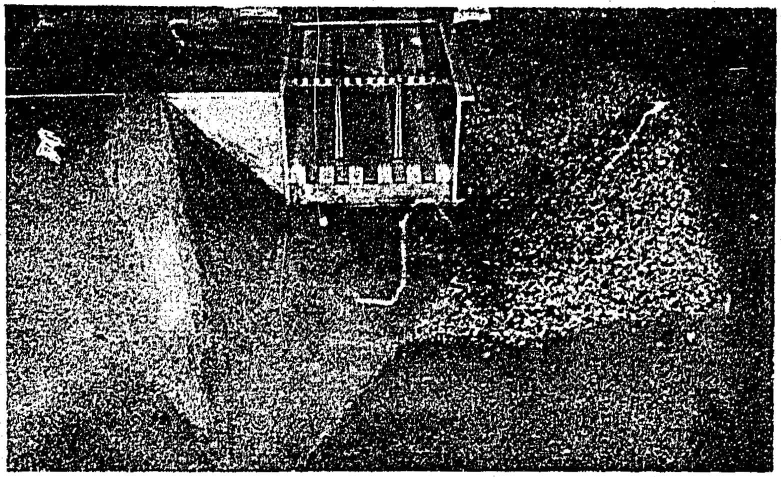
C. Scour after 3 hours model operation of outlet works. Q = 3,529 cfs



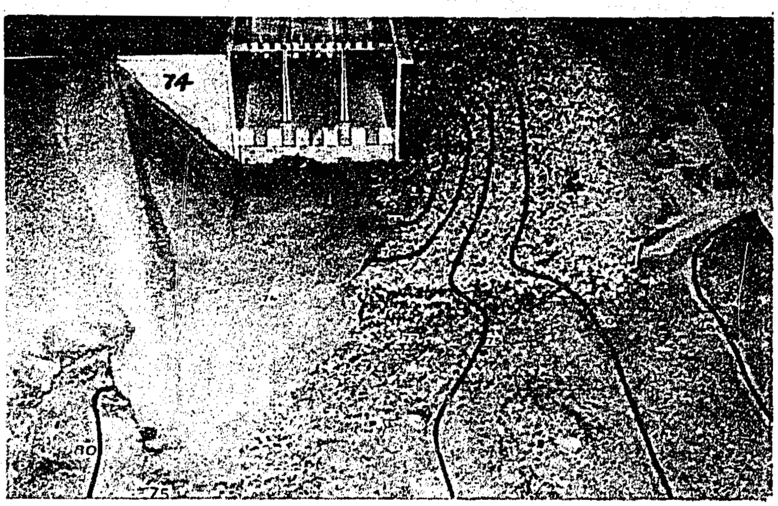
D. Scour after 3 hours model operation of spillway. Q = 8,142 cfs

PRINEVILLE SPILLWAY AND OUTLET WORKS
Outlet Flow Conditions, and Scour With 2:1 Riprapped Slope Downstream from Basin
1:24 Scale Model

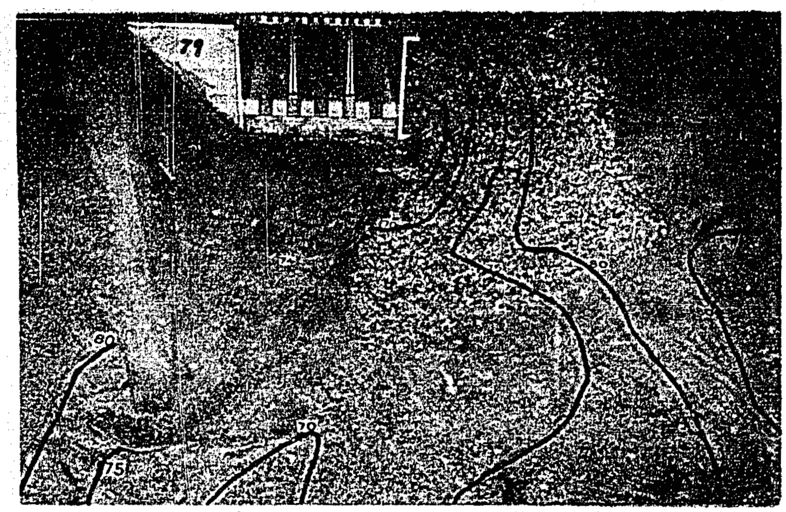
Figure 28
Report Hyd 452



A. Riprap flattens from 2:1 at basin to 3:1 at Sta. 14+75



B. Scour after 3 hrs. model operation of outlet works
Q = 3,529 cfs



C. Scour after 3 hrs. model operation of spillway
Q = 8,142 cfs

PRINEVILLE SPILLWAY AND OUTLET WORKS
Recommended Warped Riprap Slope, and Scour Downstream from Basin